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A COMPUTER BASED COST MODEL FOR THE OPTIMIZATION OF SUBSCRIBER LOOP FACILITIES IN A TELECOMMUNICATIONS CARRIER INDUSTRY

by

S.CHANDRAKUMAR

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled A COMPUTER BASED COST MODEL FOR THE OPTIMIZATION OF SUBSCRIBER LOOP FACILITIES IN A TELECOMMUNICATIONS CARRIER INDUSTRY submitted by S. CHANDRAKUMAR
in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE
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ABSTRACT

A computer based cost model has been designed for use in the optimization of subsciber loop facilities in a telecommunications carrier industry. The optimization model is developed within the framework of PNET , a network algorithm developed at the University of Texas, Austin [12,13] , considering a switching center area as the basic building block. The cost model as an integral unit of this optimization program is designed to reflect the typical environment encountered in most carrier companies. The model considers the important factors of changing technology, inflation, varying geographic conditions,economies of scale, and growth rates in arriving at the present equivalent cost per subscriber line . The PNET program evaluates the alternative routes and outputs a construction program for the first period and a capital budget for each period in the planning horizon.

The model has to be operated by trained personnel who are technically competent and fully understand each sub-system within the model to maintain the integrety of the total system and avoid errors in the input data that could prove costly. Under these conditions the model can contribute significantly to the overall savings possible from an effective capital budgeting system.

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1. INTRODUCTION

1.1 Purpose

This study represents an integral part of the total system to develop a capital budgeting model for the telecommunications network within an urban area (e.g. city). The total system will have the capability of forecasting telecommunications demand by switching center area and pinpointing the demand within the switching center area. The short term forecast (over the immediate three years) which pinpoints the demand within the switching center area will serve as the basis of the optimization model for budgeting purposes and the recommendations for actual physical plant to be installed. This information will represent the basis for the development of a construction program. Figure 1.1 is a schematic of the basic steps in the capital budgeting process.

The specific purpose of this study is to design the cost model as an integral sub-system of the total optimization model.

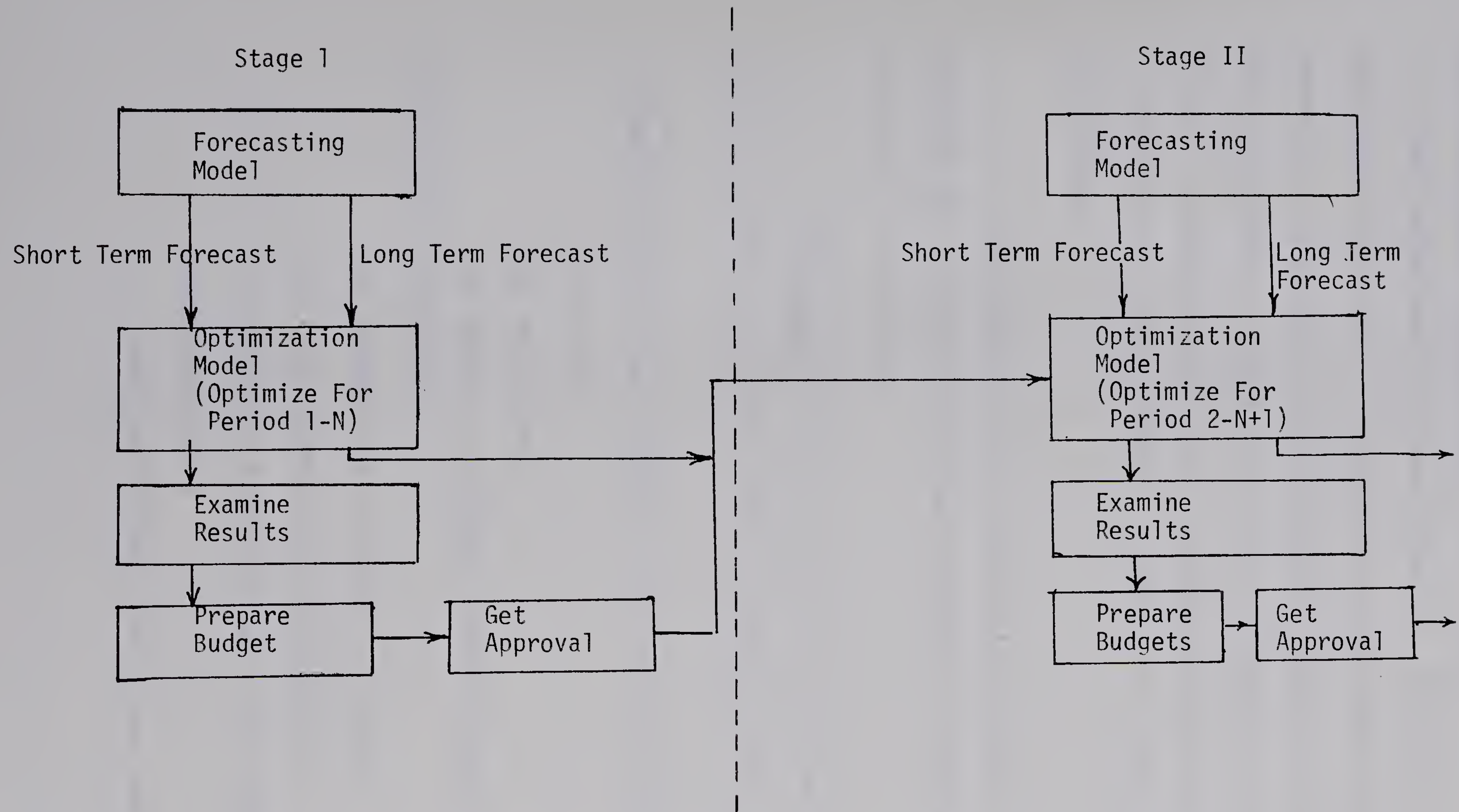


Figure 1.1 Schematic Representation of the Computer Based System For The Development of A Capital Budget For the Subscriber Loop Facilities.

1.2 Background Information

The telecommunications industry is highly capital intensive and most of the facilities have a life span in excess of 20 years. In addition the industry experiences major advances in technology on a continuing basis. These factors emphasize the need and the difficulties experienced in designing a near optimal strategy for physical facilities.

Telecommunication facilities consist of a physical network that allows verbal and written communication between users of the system.

Telecommunications plant can be best classified under two major headings from a costing point of view.

1) Support facilities (service and administration)
   - (a) land,
   - (b) buildings,
   - (c) office furniture and equipment, and
2) Operating facilities
   - (a) subscriber station equipment
   - (b) subscriber loop facilities,
   - (c) exchange trunking and toll trunking facilities, and
   - (b) local switching facilities (central office).

The support facilities include all physical facilities necessary to perform the administrative and service functions such as accounting, corporate planning, research and development and engineering. Support equipment (e.g. vehicles and tools) required as part of the direct functions performed by plant personnel should be allocated directly to each class of plant.

The subscriber station equipment represents the equipment utilized by the subscriber at point "A" to communicate with the subscriber at point "B". The network facilities (outside plant, station connection and central office equipment) represent the telecommunications equipment necessary to transport the message from point "A" to point "B". For ease of developing an optimization model, the following classifications as outlined in Figure 1.2 are useful.

1.2.1 Classification of plant

Telecommunications plant within an urban area may be classified under the following categories:

1. subscriber station equipment,
2. subscriber loops,
3. local switching,
4. exchange trunking - between exchanges,

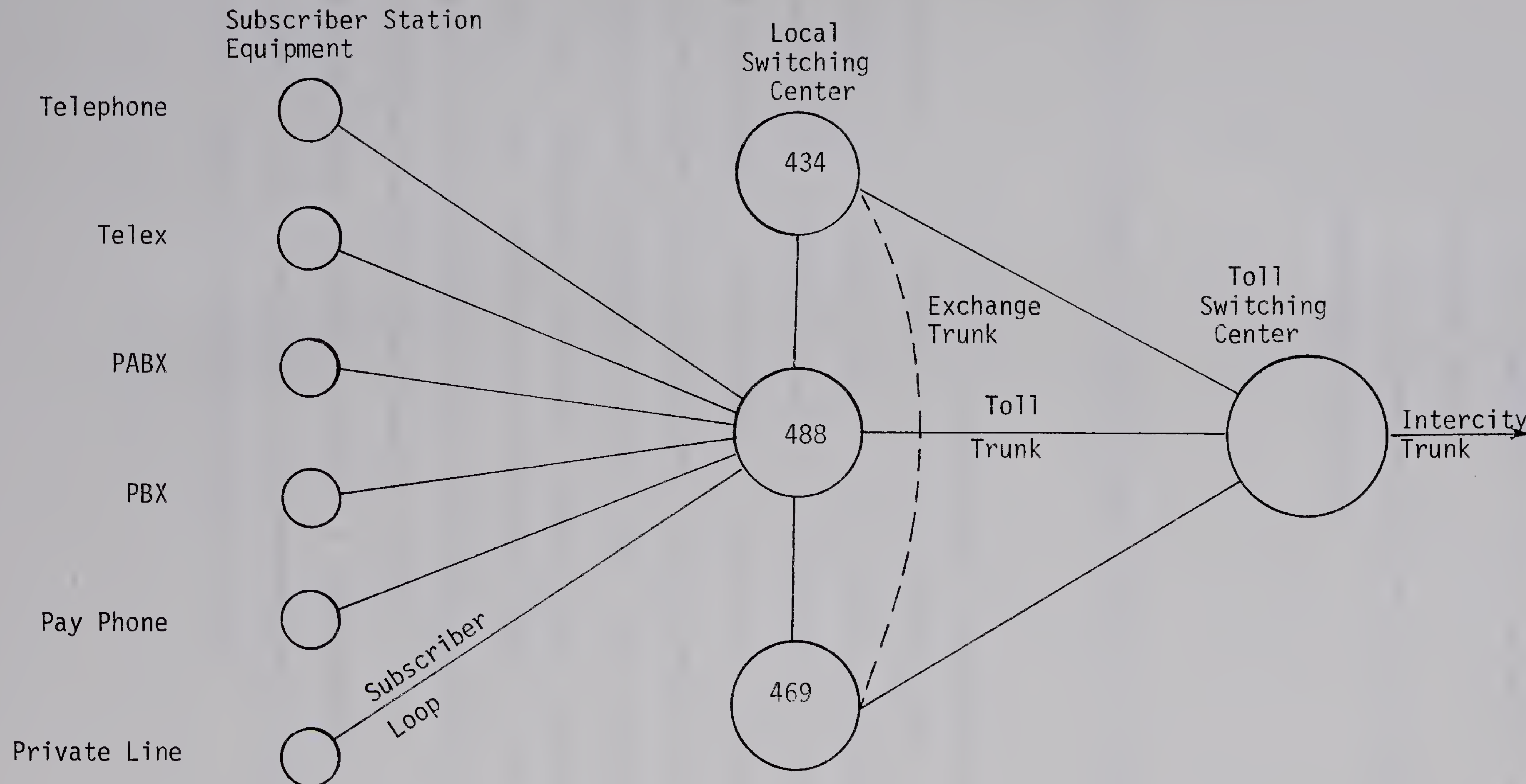


Figure 1.2 Physical Plant Facilities Within a Telecommunications Network

5. toll connecting trunks to local exchanges,
6. toll switching (toll exchange switching centers) and,
7. toll trunking (connecting trunks between toll switching centers)

1.2.2 The Method of Optimization Within an Integral System

The switching center area (exchange area) is considered the critical building block within an integral system (an exchange area is the area serviced by an individual switching center). Therefore, all information with respect to the design of a near optimal network such as forecasting data and equipment requirements will be generated by switching center area. The interaction between other individual switching center areas within the system (e.g. city) and the impact of each area on the toll system must be carefully monitored and converted into capital and operating budget requirements. Figure 1.2 is a schematic of the physical facilities within a telecommunications network. Figure 1.3 is a schematic representation of the switching center area as a building block.[23,24]

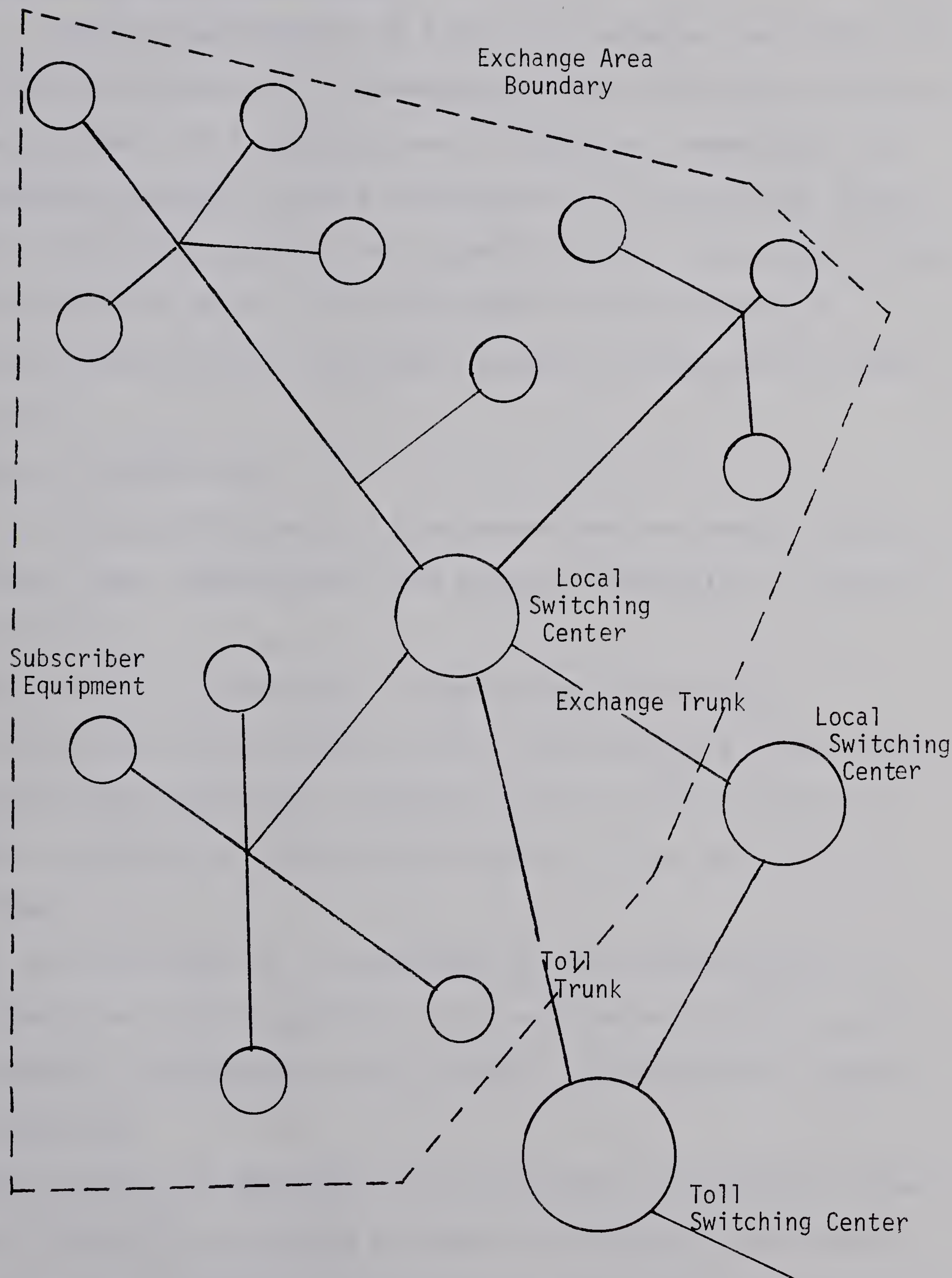


Figure 1.3 The Switching Center Area As A Building Block

1.3 Scope and Methodology

In the development of the total integral model for the optimal placement of telecommunications facilities within an urban area the first step was to develop a model for the optimal placement of the subscriber loop facilities within the switching center area. Figure 1.4 is a schematic of this optimization model. The development of this model is represented by two individual studies in addition to this study.

These studies are:

1) Bhatt,D.N,Forecasting Telecommunications Demand within an Urban area, Unpublished M.Sc Thesis, University of Alberta, 1978.[4]

This study has developed a system for forecasting telecommunications demand within the switching center area. This demand forecast represents part of the input data to the optimization model and is stored in the data bank in Figure 1.4.

2) Vijayanandan, V, A Technique for the Optimization of Subscriber Loop facilities in a Telecommunications Carrier Industry, Unpublished M.Eng Report, University of Alberta, 1978.[27]

This study has developed the functional structure as shown in Figure 1.4 including programs to operate a) the input conversion system, b) the master control unit, and c) the output conversion system.

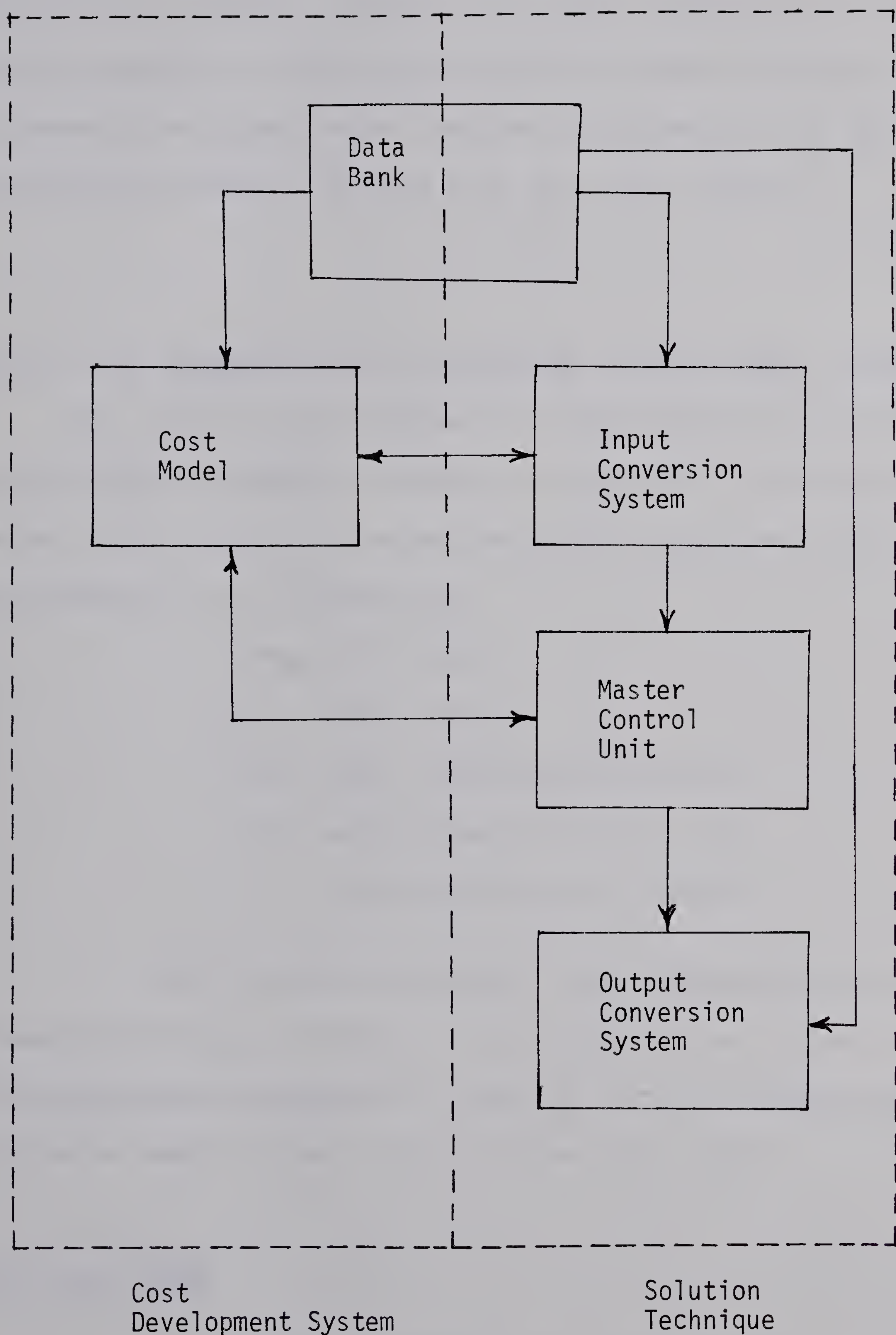


Figure 1.4 Schematic of the Optimization Model for Telecommunications Facilities Within an Urban Area

The main purpose of this study was the development of the cost model. However, to insure continuity of the total system a significant amount of time was devoted to the framework outlined below and to the selection of the optimization model outlined in the next chapter.

1.3.1 The Framework for the Design of the Total System

The optimization system is sub-divided into functional components in order to design the system in an organized manner. The total optimization model constitutes the following as its components:

1) the data bank,
2) the cost model,
3) the input conversion system,
4) the master control unit, and
5) the output conversion system.

The interaction among these components are shown diagramatically in Figure 1.4. A discussion of the organizational structure is useful for the disciplined approach used in the design of the Cost Model.

The Data Bank

The data bank will include the following information:

1) the forecast data,

2) the existing network,

3) the possible routes to lay cable,

4) the topographical details,

5) specifications as applied to the outside plant, and

6) the cost information and other general information.

1) The Forecast Data

The forecast data includes the short term forecast (three years) and the long term forecast (covers ultimate growth in the switching center area) furnished by the forecasting model. The forecasted demand is stored in the data bank and displayed by a rectangular coordinate system, so that it is easily retrieved by other components of the system. The forecasting model has direct interaction with the optimization model in this sub-system .[4]

2) The Existing Network

The existng network of outside plant is represented on the same coordinate system. Different subscripts and numbers will identify each type of plant. The forecasted demand is identified by the coordinates of the nodes to which it is linked.

3) <u>The Possible Routes To Lay Cable</u>

The possible routes will be included in the network on the same coordinate system. If any of these routes are found unsuitable after the first few iterations they will be eliminated from the network. This process will greatly reduce the number of nodes and arcs to be handled in the subsequent iterations.

4) <u>The Topographical Details</u>

The topographical details will include the terrain (valley etc.) depicted on the same coordinate system as the forecast data. These details will be used in the selection of the least cost routes from the set of possible routes to place physical plant. The direct labour times will be linked to the geography of that area.

5) <u>Specifications As Applied to the Outside Plant</u>

The specifications include all information pertaining to the physical plant such as: the available cable sizes, gauges and the manhole spacing requirements.

6) <u>The Cost Information And Other General Information</u>

Information pertaining to the company, such as overhead and general industry indexes that are necessary in the cost calculations will be stored and updated on a

regular basis.

The Cost Model

The specific technology used within any class of plant has a significant impact on costs. The cost model considers the effect of various technologies and computes the arc cost (arcs are used to denote the physical plant between two terminal points) based on changing technology. The master control unit with the help of the 'PNET' program evaluates the effect of various technologies and decides on the appropriate type of plant to be used in the subscriber loop. Basically, this system contains a cost function or functions to calculate the appropriate arc costs to feed into the master program. The main output from the system designed in this study will be the cost per subscriber loop (which is usually a cost per cable pair) between each pair of nodes in the existing and feasible alternative routes in the network. Costs are compared on the basis of a present value analysis (net present value).

For example, assume cable plant is under study, the following information from the data bank is required to compute the cost per subscriber loop as a function of the type of cable and size of cable under varying geographic conditions. They are:

A. Information pertaining to the network:

1) layout of the cable network:

2) geographic conditions, topography etc. pertaining to the existing and feasible alternate routes;

3) distance between nodes i and j;

4) information as to the amount of unutilized capacity existing;

5) the number of new additions feasible, considering the time span;

a) with respect to the number of cable pairs , and

b) with respect to the number of conduits.

B. General information, such as:

1) the inflation rate;

2) the rate of growth of the company and the industry;

3) the cost of capital;

4) the debt ratio;

5) the planning horizon; and

6) regulations by the regulatory bodies; and

C. the impact of technology on cable developments.

The input conversion system will furnish the relevant information and activate the cost model to compute the costs.

The Input Conversion System

The input conversion system [27], converts the information from the data bank and that provided by the cost model into a usable form for use by the master program, PNET. It contains the necessary computer programs to transform the raw data into a suitable format for the 'PNET' program. In the first iteration, the input conversion system invokes the cost model to compute the appropriate costs by specifying the details of an arc. In the subsequent iterations, the master control unit interacts directly with the cost model. Note Figure 1.4.

The Master Control Unit

The master control unit contains the master optimization program PNET and other programs [27] to perform the necessary iterations. The results of the first iteration will be a basic feasible solution . Since the cable sizes are available in discrete amounts, the master control unit will be updating the arcs after every iteration and consult the cost model for new cost data. Once the iteration starts, this unit will be in constant interaction with the cost model until the optimal solution is obtained. The output will then be fed to the output conversion system.

The Output Conversion System

The function of the output conversion system [27] is to convert the near optimal solution into an identifiable form, for practical use. It involves the reversal of the process utilized in the input conversion system. The dummy nodes will be removed from the network and the amount of flow in the different arcs between any two nodes will be translated into their corresponding plant type. The nodes from which the flow is occurring will be translated into the proper manholes or access terminals. This information will be used to output the capital budget and construction program by period. The output conversion system contains the necessary computer programs to accomplish the above functions.

2. DEVELOPMENT OF THE OPTIMIZATION MODEL

2.1 Overview of the Total System

The optimization model to be designed for the telecommunications industry will be developed considering the switching center area as the basic element and the city as the integral system. This section outlines the characteristics of the total model.

2.1.1 Output of the Optimization Model

The optimization model will output:

1) the additions/replacements to be made to the existing plant throughout the planning period,
2) the nature of these additions, i.e., the size and type of changes to be made during each period,
3) the timing of the additions/replacements, and
4) the investment costs for each period within the planning horizon under the near optimal plan.

2.1.2 Inputs to the Model

The model requires the following input information in order to accomplish the functions indicated in the previous section:

1) network information including
   a) the geographic area considered,
   b) the location within the specified area,
   c) the existing and utilized plant capacities in the area, and
   d) the possible future routes,
2) the cost information such as:
   a) the cost by size and type of plant,
   b) the prevailing and expected labor rates,
   c) the growth rate of the firm,
   d) the cost of capital, and
   e) the rate of inflation,
3) the number and duration of the periods in the planning horizon,
4) the forecast data comprising:
   a) the locations of demand points,
   b) the total demand up to and including the first period in the planning horizon, and
   c) the incremental demand for the remaining periods, and
5) technology assessment, i.e.,
   a) the expected number and type of telecommunication carrier technologies for each

period, and

b) the cost trends of the past in the case of each technology.

The optimization model will develop a near optimal capital investment plan based on the information discussed above. In developing such a program, the model will consider the entire planning period of thirty years and the impact of customer demand and future technologies on the physical plant.

2.2 Problem Formulation

The philosophy adopted in formulating the optimization of subscriber loop facilities in a telecommunication industry is listed below:

1) The switching center area, in most towns, can be divided into a series of arcs.

2) The arcs can be identified by beginning and ending nodes, both of which represent a point where lines can be branched (e.g. manholes, access terminals).

3) Demand is aggregated at certain convenient points and these points have to be identified based on factors such as the city development plans, the type of customers in the area,etc.

4) The goal of the company is to determine the minimum cost route as opposed to the minimum length route.

However, usually, both routes are identical.

Figure 2.1 portrays a representative switching center area, with its constituent arcs and nodes. If the total number of periods in the planning period is equal to 'N', the total cost function can be simply described by,

$$Z = \sum_{n=1}^{N} \sum_{i=1}^{m} \sum_{j=1}^{m} (\Delta_{ijn}.F_{ijn} + C_{ijn}.X_{ijn})$$

where,

'n' is the subscript representing the period,

'i','j', are the beginning and ending nodes of the arc considered,

'm' is the total number of nodes in the entire area,

'C_{ijn}' is the variable cost per line for the arc i-j in period, n,

'X_{ijn}' is the capacity of plant installed in period, n, between nodes, 'i' and 'j',

'F_{ijn}' is the fixed costs of installing plant across i-j in period, n, and

$\Delta_{ijn}=0$ if $X_{ijn}=0$

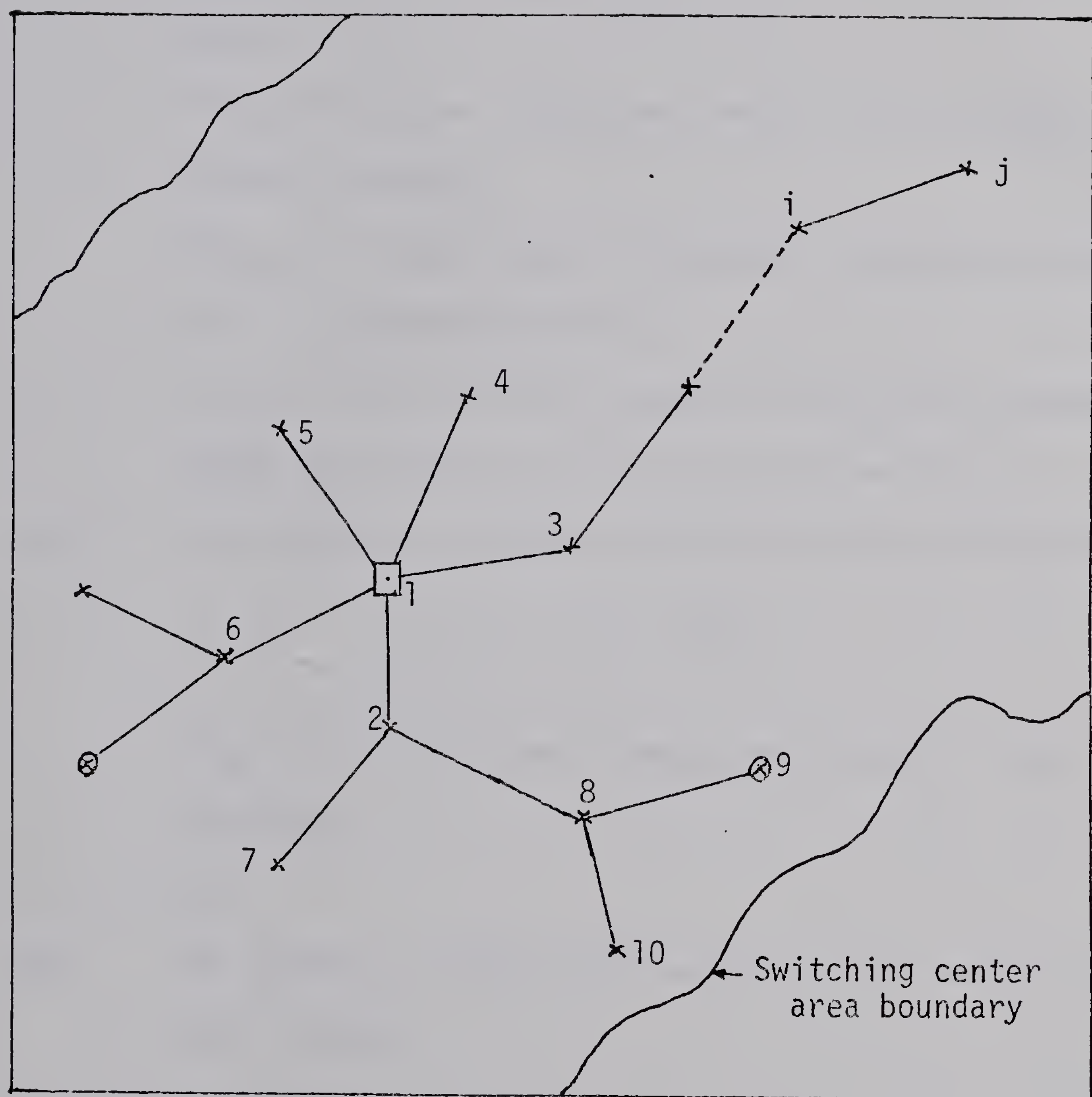
$\Delta_{ijn}=1$ if $X_{ijn}>0$

The constraints on this simplified objective function, which is to be minimized, include:

(i) non-negativity of arc capacities, i.e., $X_{ijn} \geq 0$,

(ii) the dependency of costs, C_{ijn}, on the actual capacities, X_{ijn},

(iii) the relationship between existing plant,



⊡ Switching Center

⊗ Demand Points

× Nodes, numbered 1,2...,m
1-2,1-3,... Arcs

Figure 2.1 Representation of Subscriber Loop Facilities as a Series of Arcs

additions/replacements and total plant at the end of a period, which is,

$$P_{ijn} = P_{ij(n-1)} + AP_{ijn} - RP_{ijn}$$

where

"AP_{ijn}" is the additions made in arc segment i-j during period, n

"RP_{ijn}" is the amount of plant retired in the arc i-j during period, n

'P_{ijn}' is the total capacity of plant between nodes 'i' and 'j' at the end of period, n,

(iv) the demand requirements which can be stated as

$$\sum_{i=1}^{m} P_{ijn} \geq D_{jn}, \text{ where}$$

'D_{jn}' is the total demand at node 'j' upto period, n,

and,

(v) the sizes of plant available in the market (e.g. cable sizes).

2.3 Alternative Systems Studied

Two alternative systems, namely, the Simplex method of linear programming and the network analysis approach were studied for the problem formulated as outlined in the preceding section.

2.3.1 Simplex Method

This system involves utilizing the simplex algorithm, developed by George B.Dantzig, for solving the optimization problem [11,16,28]. Computer packages based on this algorithm are available in almost all computer installations.

Under this method, the costs are initially assumed to be linear. After one run with the program, the results are examined to see whether or not the costs and the flow for all the arcs match and if the plant size additions recommended are available in the market. If not, the plant capacities and the costs are then updated to correspond to the next higher size available. The resulting problem is again solved using the simplex method. This process is repeated until all the arcs in the network satisfy the constraints.

2.3.2 Network Analysis Approach

This approach utilizes the integer programming methodology, PNET, developed at the University of Texas, Austin [12,13]. This formulation requires the problem to be stated as a network flow problem. The network problem must be of the form shown in Figure 2.2. All the flows are assumed to emanate from a super-source (shown by "1" in the diagram). The fundamental constraint in this network is that the net inflow into a node equals the net outflow. All the

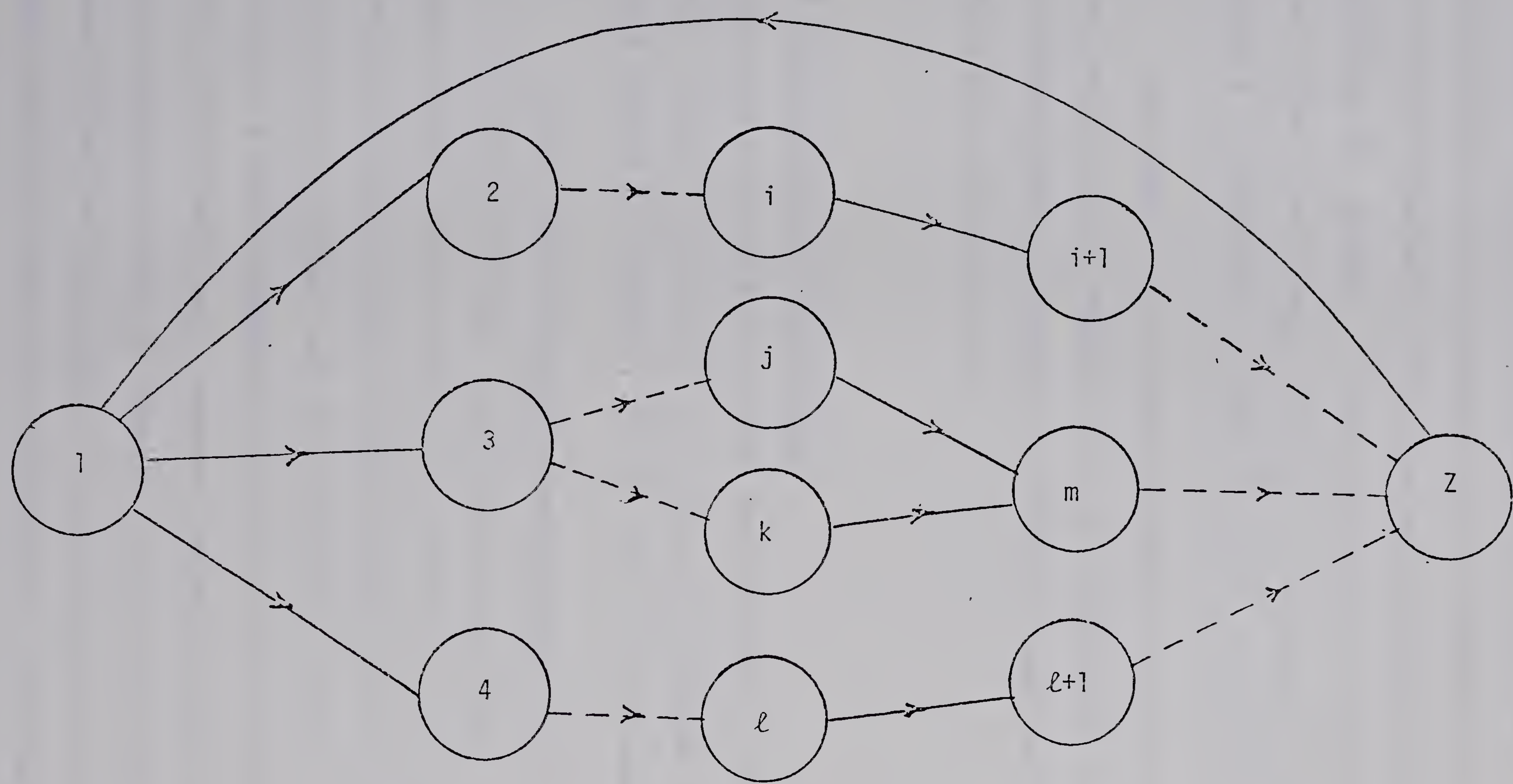


Figure 2.2 Basic Structure of PNET, The Network Algorithm

flows ultimately go to the super-sink, which in turn is connected back to the super-source to complete the cycle. A unit cost is attached to each arc and the cost of an arc is computed by the product of the unit cost and the flow across the arc. The flow through any arc in the network can be restrained by specifying lower and upper bounds for the arc.

The PNET program uses a simplex primal algorithm and is specifically designed for the solution of minimum cost transshipment problems. It outputs a near optimal solution and the total cost.

2.3.3 Evaluation of Alternatives

The two alternative systems were compared considering several criteria, mainly 1) the ease of operating the model, 2) the validity of results, and 3) the cost of operation.

Since both the simplex methodology and the network model are basically linear programming algorithms, they represent about the same degree of accuracy with respect to the results. Both of these methods assume that the total cost function is linear and this assumption makes it impossible to find a solution which can be mathematically proved to be the optimal. Computer packages using the simplex method are easy to operate as they are very common and most often are programmed in an interactive language. However, since the number of variables and the constraints

in a telecommunications network are likely to be very large, the cost of running the resulting model is prohibitive. Therefore, the network model was chosen for detailed study and design.

The basic network model will be modified to facilitate optimization of plant in a switching center area. Two buffer systems, one to convert the data with respect to the switching center area into a format that is required by the PNET program and the other to report the results in a usable format are designed by Vijayanadan[27] to increase the ease of operation.

2.4 Structuring the Problem

The PNET program is designed to solve simple transshipment problems. So, it cannot directly handle the problem of optimizing subscriber loop facilities in a telecommunications carrier industry. Several modifications are necessary on the physical network before the PNET program can be deployed. These changes must take into account:

(i) the customer demand,

(ii) the different time periods within the planning horizon,

(iii) the several types of technology encountered,

(iv) the various types and sizes of plant,

(v) the dependency of costs on the size of plant installed, and

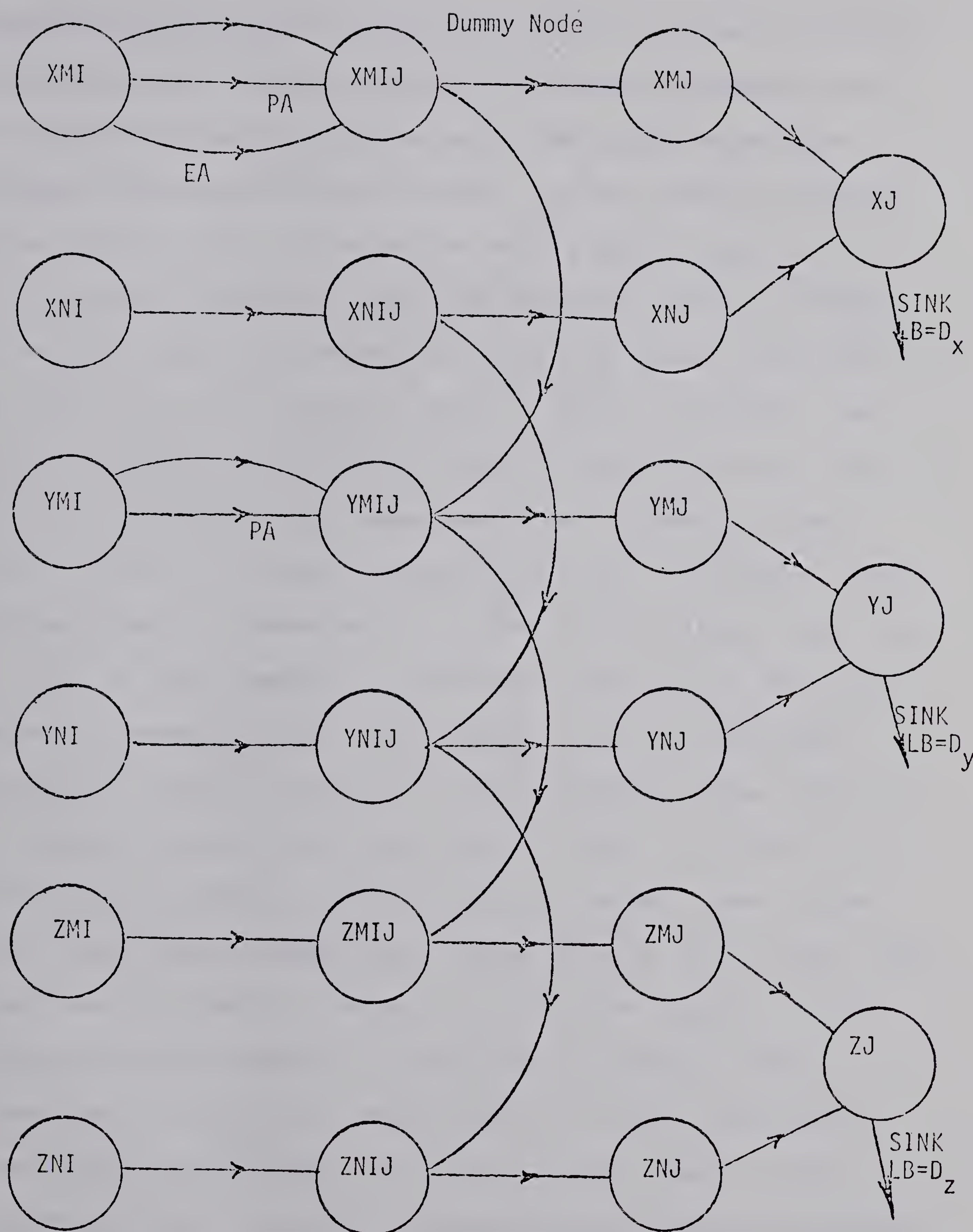
(vi) the existing plant.

Figure 2.3 is a schematic of an arc in the network incorporating all these factors into its structure. Customer demand is taken care of by creating dummy arcs from demand points (representing terminals) to the super-sink with the lower bound equal to the demand.

One complete network is utilized to describe one period in the planning horizon. Intermediate (dummy) nodes are created between each pair of successive nodes. This arrangement is necessary to link the different time periods with one another. The excess capacity in an arc flows through the intermediate node to the corresponding node in the following period allowing for use of the unutilized capacity in the succeeding period.

Assessment of technology is one of the objectives of the total system, and part of this study. Within each time period, parallel networks are created to designate the different types of technology available in that period. Thus the technologies compete to supply the demand forecasted.

The PNET program is an integer programming algorithm, which assumes that the arc flows (or the plant capacities) can be any positive integer. In a telecommunication industry, however, plant



LB - Lower Bound

X,Y,Z denote time periods

M,N denote technologies

D_i denotes demand in period, i

Figure 2.3 Structure of an Arc, I-J, in the Flow Network

additions/replacements can be made only in certain packages and these sizes are dictated by the market specifications. To account for such an occurrence, the plant sizes are updated, progressively by periods, in the manner discussed below. After every run with the PNET program, all the arcs in the period considered will be scanned to verify whether or not the flows correspond to a size of plant available. If the flow in an arc equals a size of plant available, the lower and upper bound for the arc are equated to the flow in the arc. Otherwise, the upper and lower bounds are made equal to the next higher capacity of plant available. These updated arcs are referred to as the primary arcs. There can, at most, be one primary arc between a given pair of nodes. There are certain fixed costs (such as trenching costs, conduiting costs) associated with installing plant that do not change linearly with the size of plant. If there is a primary arc between a certain pair of nodes, these fixed costs would have already been taken care of in the unit cost specified for the arc. Hence any additional plant to be installed will, normally, cost less to install. When a primary arc is updated, this factor is taken care of by introducing an additional arc with a cost equal to the incremental unit cost. The incremental unit cost is obtained by dividing the additional cost involved in placing the next higher size of plant available by the increase in capacity of plant. When the resulting network is run with the program PNET, flow in the new arc will indicate whether or not it is

desirable to place more plant to take care of future demand. Between a given pair of nodes, one arc will represent one type of plant (e.g. underground cable, aerial cable, buried cable).

Once again, it is important to note that the dependency of cost on actual flow and the fact that there is a fixed cost associated with installing plant imply that it is impossible to be certain whether or not the solution output by the program is optimal. The unit cost specified for an arc, initially, are those based on the smallest quantum of addition possible. This cost is computed by dividing the cost of plant of the smallest size by the capacity. If the flow, after a run with PNET, is found to exceed the flow used as the basis for cost calculations, the cost is revised to correspond to the new size of plant. For example, if the cost calculations for the initial run were made based on a capacity of 600 lines (subscriber loops) and the flow in the arc was 850 lines, the next iteration is run using the cost for a 900 pair cable. This process is repeated until the flow and the cost match for all the arcs in the entire network.

Any existing plant is denoted on the network by an arc with a cost equal to the present equivalent cost calculated considering the material value less the removal charges, the operating costs, and the salvage at the end of its useful life. Initial costs are ignored because they are

sunk costs and are irrelevant in making decisions and in capital budgeting. The upper bounds for these arcs are specified to be equal to the respective capacities to signify the size available.

Figure 2.3 represents an arc that has both existing plant and an end node that is a demand point. It should be noted that it is not necessary that all arcs have existing plant or that there is demand at the ending node. The arcs denoted by "PA" represent the primary arcs or those that have been updated. The arcs "EA" denote existing plant, while the node "X J" is a dummy node created to represent the terminal with a demand "D". The sum of the flows in the arcs between a certain beginning node (e.g. XMI in Figure 2.3) and the corresponding intermediate node (XMIJ) will indicate the total installed capacity between the nodes at the end of the period in question. If the flow in the existing plant were subtracted from the total installed capacity, the resulting value will be the additions to be made in the period considered between the nodes. The flow in the arc connecting the intermediate node to the corresponding node of the following period (e.g. arc XMIJ-YMIJ in Figure 2.3) represents the excess capacity at the end of the period that can be utilized in later periods.

The operating sequence of the optimization process is explained in the next section, considering a specific technology 'M', referred to in Figure 2.3.

2.4.1 Operating Sequence

The major steps involved in the process of optimization are summarized below:

1) Obtain a basic feasible solution by running program PNET with the data supplied by the input conversion system. The output of this stage will indicate the flow necessary in each period to satisfy the forecasted demand.

2) Set the lower bound on all arcs connecting the intermediate nodes, X IJ, to ending nodes, X J, equal to the flow in the respective arcs. The symbol 'X' refers to the period the arc represents and 'IJ' is a dummy node introduced between nodes 'I' and 'J'.

3) Set the period 'T' (T is a variable that refers to the periods X,Y,Z successively) for which updating is to be done equal to one.

4) Scan all the arcs connecting 'X I' and intermediate nodes 'X IJ' in period, 'T'.
   (i) No changes are made to those arcs where the flow is zero.
   (ii) If the flow in any of these arcs equals a size of plant available, equate the lower and upper bounds for the arc to the flow. Otherwise, set lower bound and upper bound

equal to the next higher capacity of plant available. These arcs are referred to as primary arcs. Invoke the cost model to obtain relevant unit costs for these primary arcs. Create a new arc between all pairs of nodes linked through a primary arc. This is necessary to allow for installation of more plant if it were found to minimize the cost in the next iteration. The cost on the new arc will be equal to the incremental unit cost of increasing plant capacity to the next higher size available. The incremental unit cost is defined as the difference in cost between two sizes of plant divided by the corresponding difference in size.

5) Run the program PNET with the output of stage (4) to obtain a new solution set.

6) Scan all the non-primary arcs of period 'T' in the new solution to check how many of these arcs have a flow greater than the specified lower bound.

   (i) If none of the arcs have flow in excess of the lower bound, proceed to step (9).

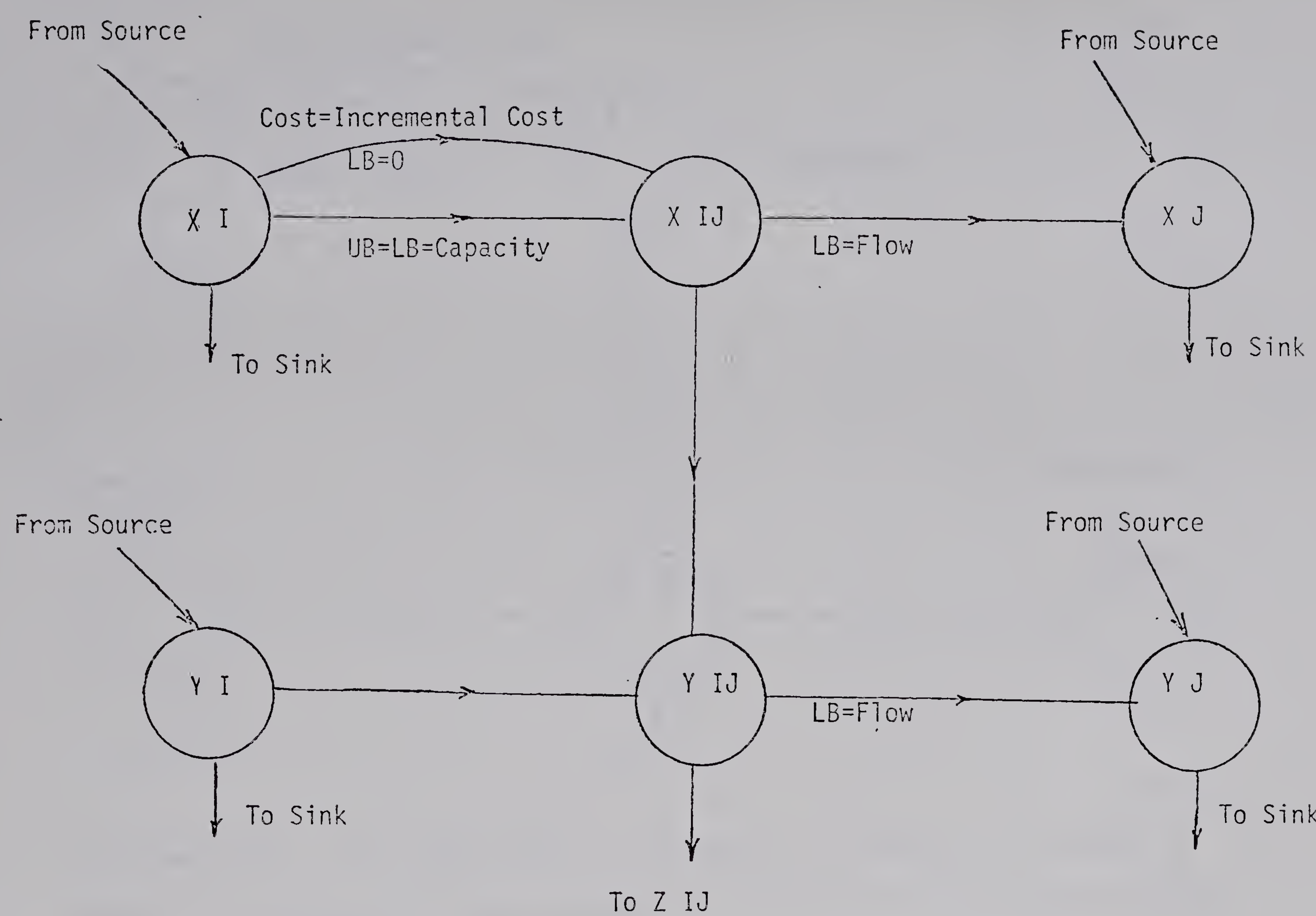
   (ii) If there is at least one arc with flow more than the lower bound continue with step (7).

7) Adjust the lower bound on all the non-primary arcs. The new lower bound will be equal to the flow, if plant of that capacity is available. Otherwise, the lower bound will equal the next higher size of plant. Activate the cost model to obtain the relevant unit cost for the arc. No additional arcs need to be introduced because no upper limit is specified for these arcs.

8) Run the program PNET with the output of step (7) to obtain a new solution and return to step (6).

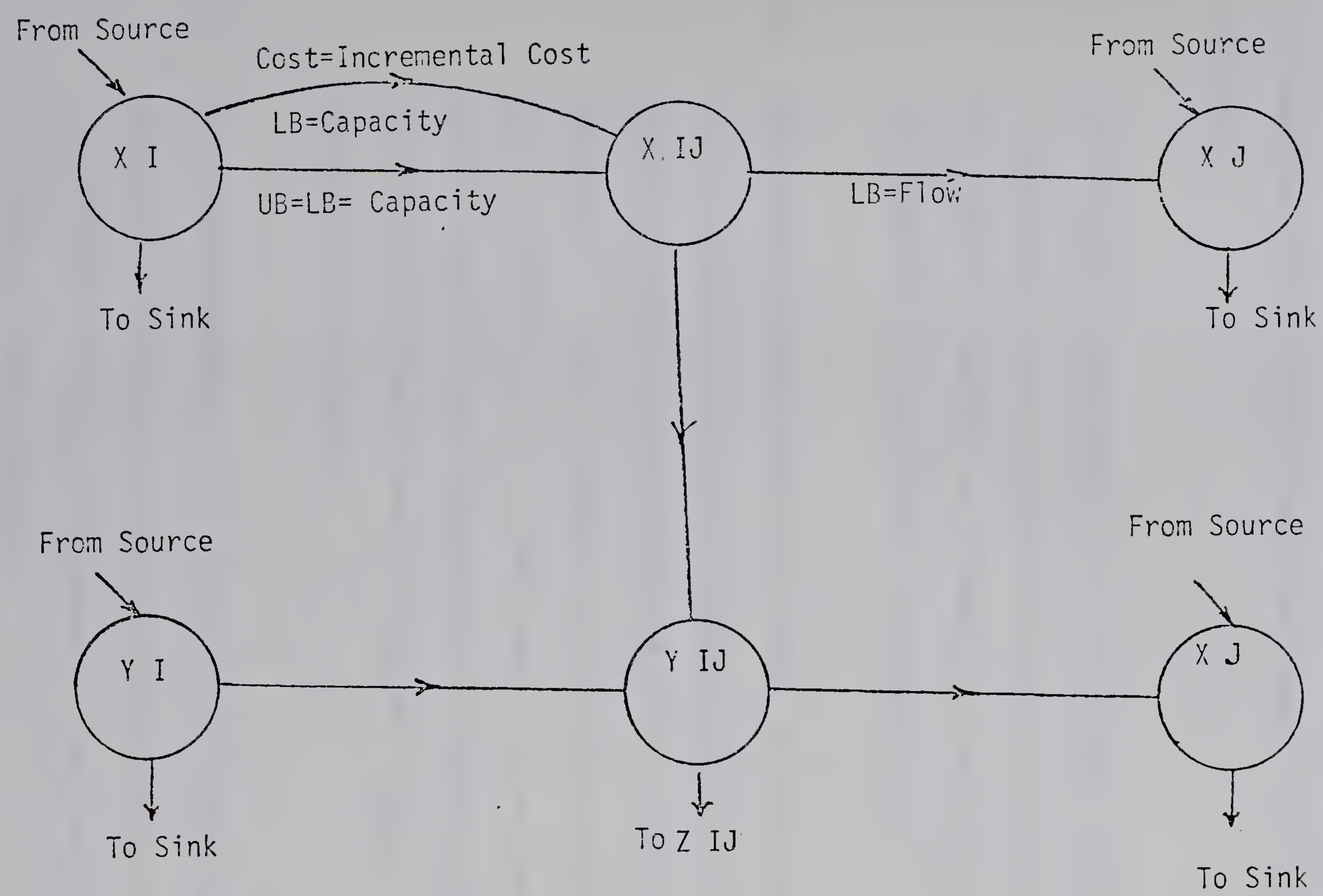
9) Increment the period indicator by one, i.e., the new value of 'T' becomes 'T+1'. If the new value of 'T' exceeds 'TMAX', the number of periods in the planning horizon, the final solution has been obtained and can be input into the output conversion system . Otherwise, return to step (4).

Figures 2.4 and 2.5 show schematically the state of the arcs at the end of stages (4) and (7) respectively.



LB = Lower Bound, UB = Upper Bound, X = Period 1, Y = Period 2, Z = Period 3.

Figure 2.4 The State of a Representative Arc After the Fourth Stage of Operation



LB = Lower Bound, UB = Upper Bound , X = Period 1, Y = Period 2, Z = Period 3

Figure 2.5 The State of a Representative Arc at the end of the Seventh Stage of Operation

3. THE COST MODEL

The cost model is analysed in relation to the following important considerations and developed in a suitable format to perform its intended function. These considerations include:

1. Technology assessment - the specific technology used within any class of plant can have a significant impact on costs. A method of assessing the impact of technology is described in section 3.1.

2. The structure of the cost model in relation to 'PNET' : In the case of already existing plant the carrier company tends to be 'locked into' the past investments. The 'PNET' model recognizes this fact and treats the past investments as a sunk cost. These past investments have a capital cost equal to the depreciated value of the material cost less the removal costs, for economic evaluation purposes.

3. The development of the basic cost functions : There are several important factors that shall be considered in the development of the basic cost functions. These include:

   a. Economies of Scale - for example;

1) the installation cost per pair varies significantly as a function of cable size, and

2) the material cost per pair varies significantly by gauge.

b. Age of plant in service - The age of plant in service directly affects costs and will be reflected in the cost model through operating costs and by the depreciation schedule.

c. Excess capacity - Excess capacity may result for several reasons (e.g. economies of scale, growth rates, inflation and technology) and have an impact on costs.

d. Growth Rates - The rate of growth within switching center areas has a bearing on costs. Growth rates also directly affect the age of plant in service and the excess capacity considerations. However, the impact of the growth rate is implicitly considered by the forecasting model and hence needs little consideration in the actual cost model.

e. Geographic Location - Geographic location may

result in differences in costs through differences in such factors as;

1) soil conditions,
2) labor rates,
3) weather conditions,and
4) building and land costs.

The basic cost functions include all of the above factors. [6,7,8,23]

3.1 Technology Assessment

Technology can have a significant impact on the analysis of alternative investment decisions.

3.1.1 Technological Developments

To quantitatively state the impact of technology becomes very difficult due to the many interacting parameters affecting changes in technology. These include:

1. Direct Competition

Many organizations rely primarily on advanced technology for competitive advantage and therefore concentrate major resources on fostering research and development. Clearly a shift in the basic competitive strategy of an industry is likely to have a strong influence

on the rate of technological progress.

2. Corporate Strategy

It is clear that technological progress does depend on prevailing corporate strategy, which is in turn conditioned to some degree by non-technological factors.

3. Sunk Costs

The telephone companies have invested large sums of money into plant of a specific technology. These companies may be adverse to adopt an altogether new kind of technology within a short time span because of these sunk costs. The inertia of these past investments will affect the replacement cycle of existing equipment and the learning curve characteristics of the industry which in turn affect the rate of technological change.

4. National and international Political and Economic Environment

Political and économic environments are major controlling factors affecting technological change. The direct impact of defence strategies and the effect of technological spin-off of these strategies on the industrial environment are very significant.

3.1.2 History of Technological Developments

To highlight some of the major technological trends, let us survey briefly the historical developments in the field of transmission medium.

1. Resistance and Induction

The early developments date back to the use of copper wire as the transmitting medium, prior to which the electrical resistance of the telephone line limited the service originally to very short distances. The first copper wire tried made a good conductor, however, it was too soft to be of practical use as it would break of its own weight when used on open wire spans. Hard drawn copper wires overcame this structural difficulty and found large-scale use starting in 1884. The induction or cross talk problem was also solved about the same time by interchanging or transposing the position of the wires in the medium.

2. Need for Placing Lines Underground and the Principle of Loading Coils

The rapid increase in the number of subscribers and the corresponding increase in overhead wires soon resulted in a move to underground circuits . The first underground cables were placed around 1890. The first cables used were large gauge copper conductors (small diameter) and an effort was made to reduce the diameter of the conductor.

The year 1900, marked the important development of applying the loading coil principle (i.e.) the insertion of

inductance in small quantities at regular and frequent intervals greatly improves the transmission efficiency.

3. Repeaters or Amplifiers

By 1911, it was apparent that a satisfactory means for amplifying the attenuated telephone currents on a long circuit would be necessary. To accomplish this a new device known as a repeater or amplifier was developed.

4. Carrier Systems

With the distance barrier solved; caring for the increasing volume of calls presented the problem of placing more telephone channels on existing facilities. The electronic vacuum tube by 1918, was available for getting carrier currents which would allow the use of a wider frequency range than the voice frequency range. Other technical advances provided a means to temper, or modulate the carrier currents with the voice currents and to reproduce, or demodulate, the voice currents at the receiving end of the telephone line. In addition filters were developed which were capable of separating into groups a mixture of currents at different frequencies transmitted over the same conductors.

Carrier systems were a substantial factor in meeting the growth requirements in exchange trunking and toll trunking where they naturally provide economies. However, recently they have been used in the subscriber loop facilities . The development of carrier systems has

significantly advanced solution to the problem of distance and costs.

5. Coaxial Systems

Another major development of the carrier principle of transmission came into use by the end of 1936. The carrier principle was applied to an entirely new type of line facility known as the coaxial cable. A coaxial system consists of a copper tube, down the center of which runs a copper wire held in place by insulating discs. It is capable of transmitting hundreds of telephone circuits.

6. Radio Relay Systems

Another type of transmission facility more recently developed is known as the microwave radio relay system. The system provides a very broad frequency band and is capable of carrying television channels and hundreds of telephone circuits.

7. Radio Telephones

Although the development dates back to the 1920's, the use in subscriber loop plant is very recent.

In summary, many improvements have been made in transmission capabilities due to the developments in the basic transmitting facility, introduction of various carrier systems and introduction of radio transmission. These changes in technology have come about in an attempt to provide a more ideal transmission system at minimum cost to

the subscribers in connection with:

(1) good quality,

(2) sufficient volume,

(3) uniform transmitting and receiving efficiency independent of the lengh of the loop,

(4) freedom from side tone,

(5) freedom from excessive cross talk and noise, and

(6) aesthetic appeal.[1]

3.1.3 Alternative Methods of Evaluating Technological Change

Companies implement technological change in an effort to minimize cost in the long run. With this idea in mind, the following two alternative methods were considered in order to quantify technological change.

The following steps outline the method adopted in the first approach. The alternate technologies considered are those that are applicable in subscriber loop plant and which are in either the application stage or the developmental stage.

Methodology

1. List all the possible technologies that are known at present or will be used in the near future in the subscriber loop plant, such as:

a) voice frequency (VF) cable pair;

b) small analogue carrier systems;

1) Anaconda 56A (7 channels)

2) Superior cont CM8 (8 channels)

c) large digital carrier systems;

1) ITT, DM32S (32 channels, 128 lines), and

2) Northern, DMS1 (48 channels, 256 lines);

d) digital radio: (e.g. Farinon SR radio);

e) cables CXR: (e.g. Lenkust 84A, 1 channel + 1 physical);

f) Vidar SCT: (e.g. 24 or 48 channel dedicated PCM); and

g) fibre optics cable.

2. For each technology, segregate the total cost into the following components and project these costs into the future.

a) the initial cost (B) consisting of:

1) direct labor cost, loadings on labor,

2) direct material cost, indirect material cost, and

3) overheads such as;

(a) motor vehicle and special tools cost,

(b) engineering cost, and

(c) miscellaneous cost (contract bills, cost shared with other utilities);

b) the operating cost or the annual equivalent of operating costs based on a life span of n years, if the plant considered is installed in years 0,1,2 ...... up to the planning horizon. The operating cost will also

have the same components (1) to (3) listed above; and

c) the salvage value of plant at the end of the life span.

d) annual depreciation for the different years considered.

The unit of measurement used herein is the cost per subscriber line per unit of distance, based on a particular capacity of plant. If the capacity, actually required is different from the particular capacity considered, then the cost per line per unit of distance will be corrected to reflect the actual cost by multiplying by a factor which is the ratio of cost per subscriber line per unit of distance of new capacity to the cost per subscriber line per unit of distance of the capacity considered. The above factors can be determined from historical cost data. Similarly the operating cost, depreciation and salvage values are determined. The data, for any specific technology, may appear as shown in Figures 3.1 and 3.2.

3. From the above figures the Present Equivalent Cost (PEC) per unit capacity of plant per unit distance in the various years can be determined for the different technologies. These PEC values may then be used as arc costs in the network formulation as suggested in section 3.4.1.

In the second approach, which is the approach suggested herein, the present equivalent costs are not segregated as is suggested in the first method. Instead, the

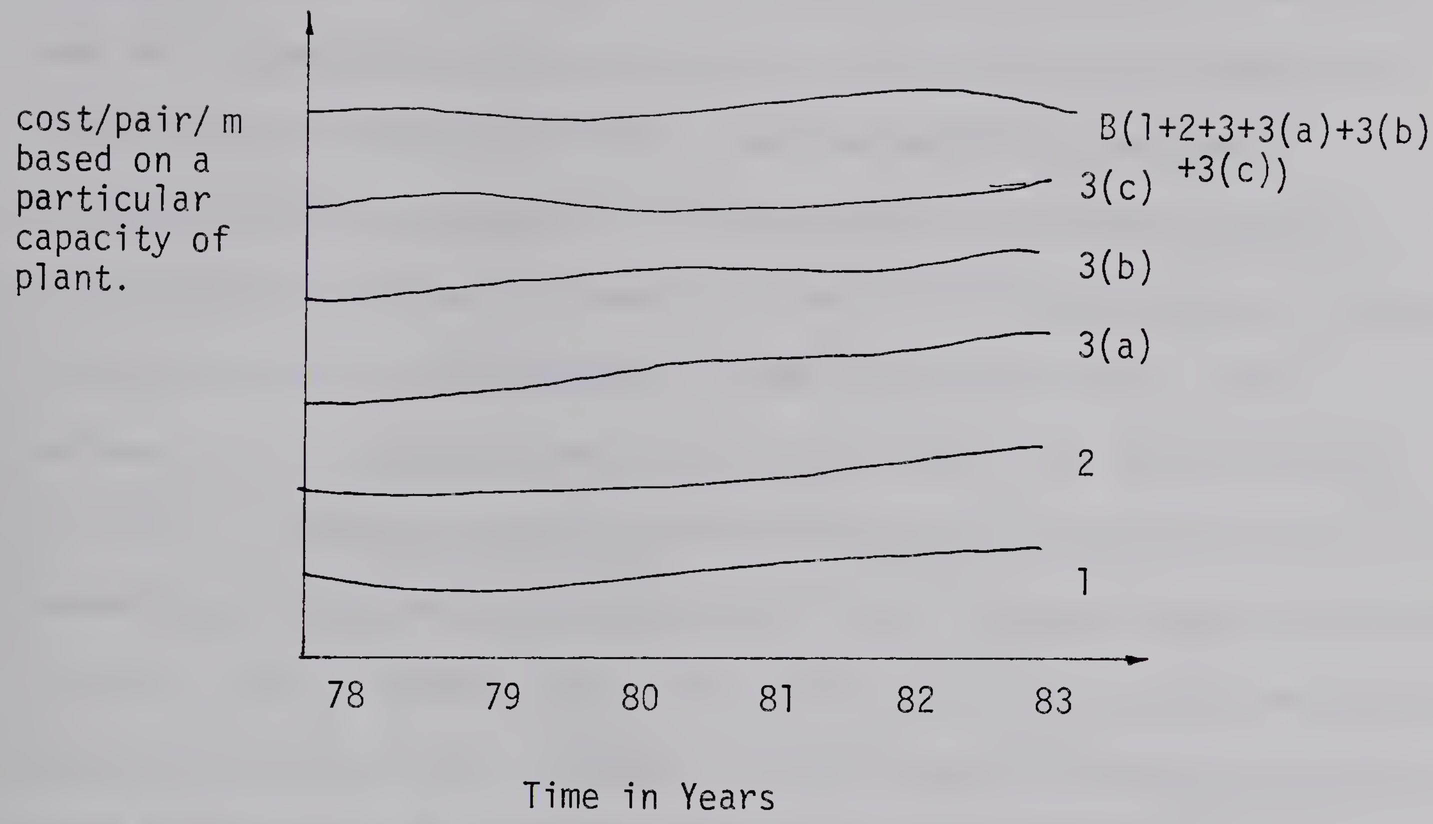


Figure 3.1 Initial Cost - Time Functions for Technology X

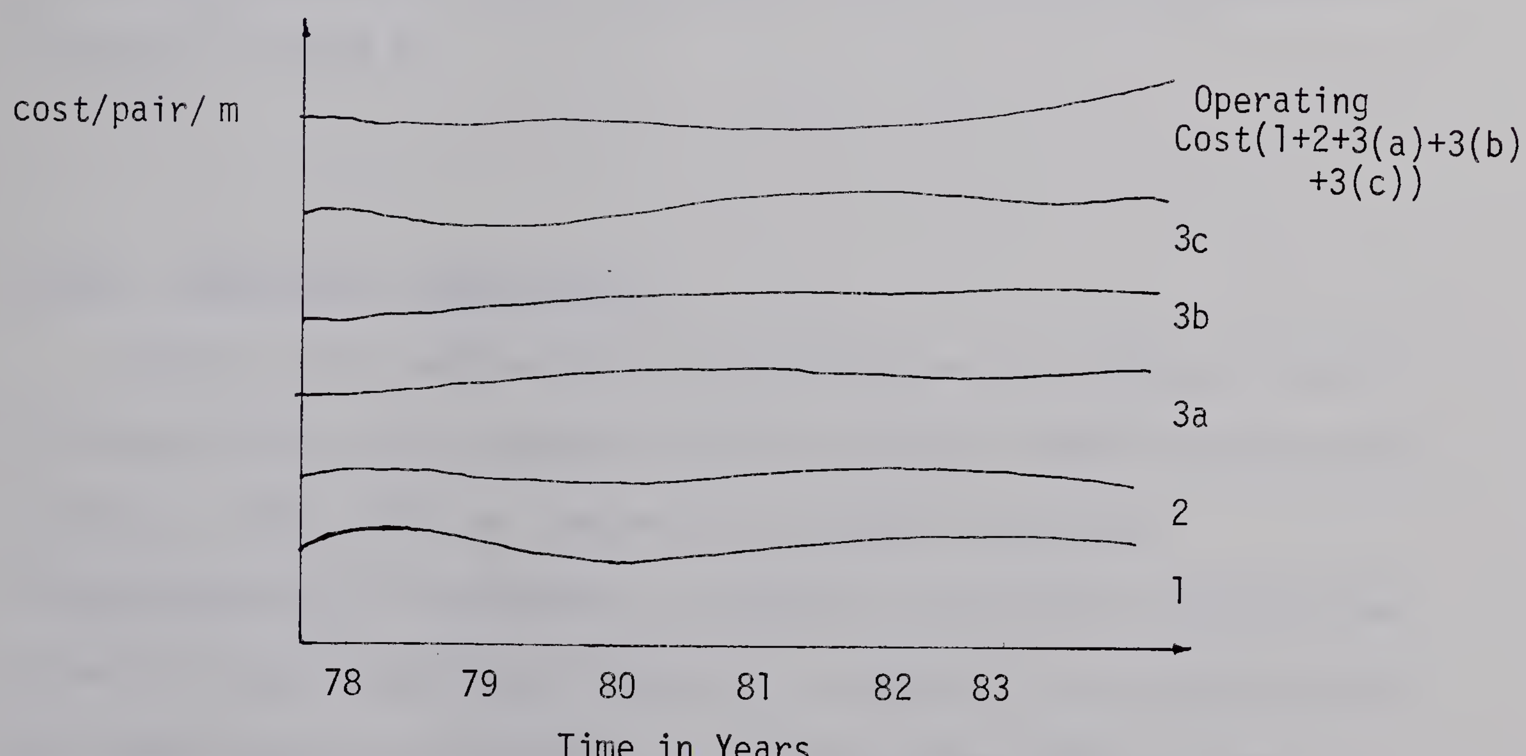


Figure 3.2 Operating Cost - Time Functions for Technology X

overall effect of technology on cost is measured by making use of technology survivor curves. The cost per subscriber line per unit distance forms the inverted 'S' shaped envelope curve gracing the technological survivor curves. This envelope curve is used to find the technological growth factor which is incorporated into the cost model. This method offers significant advantages over the first method in that it concentrates on determining the overall effect of technology on cost per subscriber loop without analysing the specific micro details of the individual technology survivor curves. In addition it saves on the number of nodes and arcs that would have to be considered using the first method , thereby significantly reducing the computer time required. The sections that follow describes this selected method in detail.[2,17,26]

3.1.4 Assessing Technology

When a new technology is introduced its initial costs are usually at the maximum level, however over the years the initial costs tend to decrease through technical improvements and economies of scale. The present equivalent cost of each technology drops to a minimum total cost point and then tends to increase in costs giving way to the introduction of new, more efficient technologies. As an illustration, the capital costs of a particular technology behaves as shown in Figure 3.3. Initially the costs will be

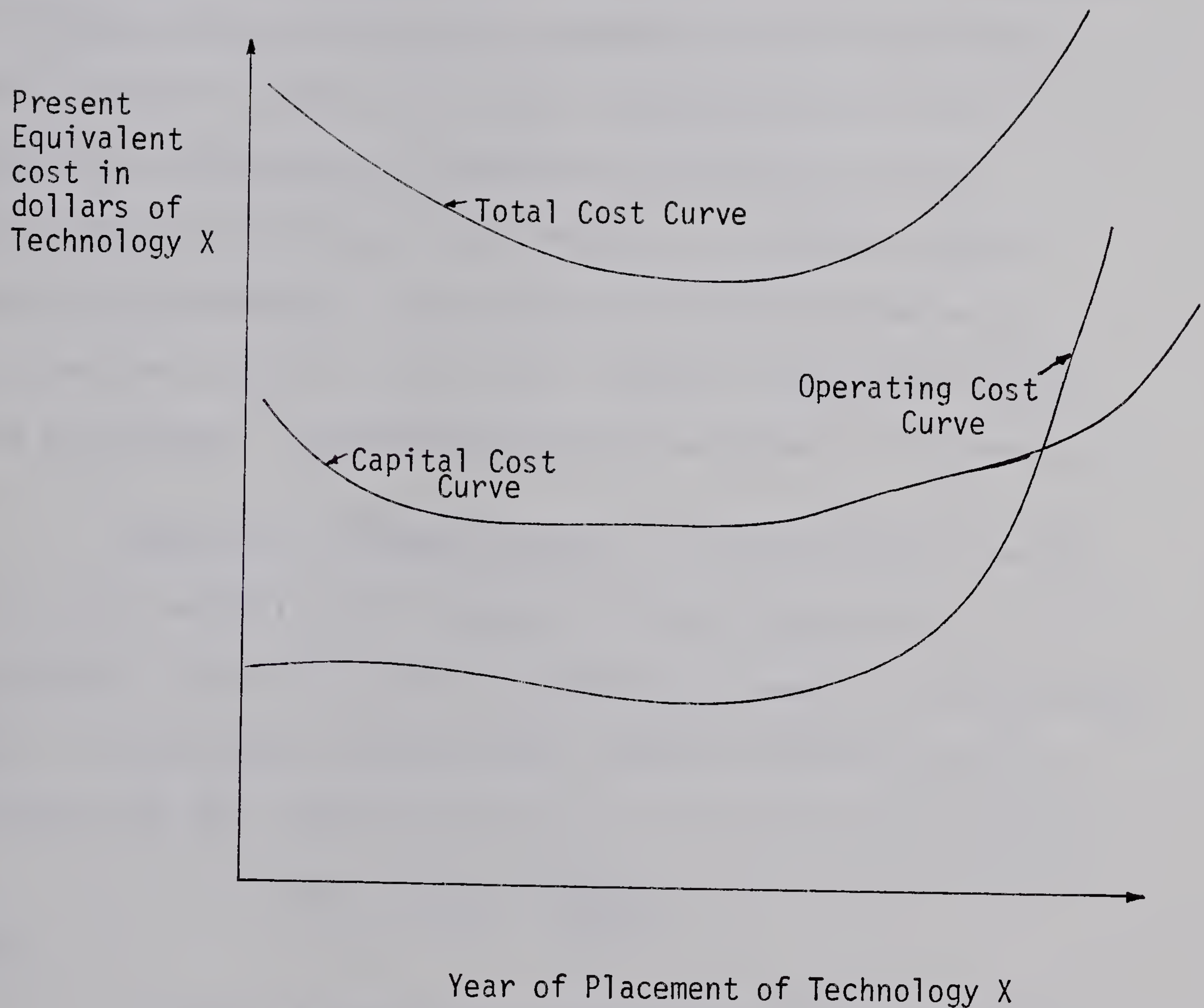


Figure 3.3 Present Equivalent Cost of Technology 'X' Versus Year of Placement

high, followed by a minimum cost period and an increase as the technology becomes obsolete and the manufacturer phases in new technologies. Similarly, the initial operating costs are normally high due to debugging and personnel being unfamiliar with the technology. However, once the personnel are trained and the debugging process is over operating costs decrease. Later, with the introduction of a new technology the operating costs will rise due to the unavailability of spare parts except by special order resulting in makeshift arrangements and an increase in shut-down time. The total costs, which is the sum of the above two curves, behaves basically as shown in Figure 3.3.

Heuristic reasons suggest an exponential law of social and technological change. In most cases the exponential phase of change eventually comes to a saturation level. A convenient mathematical function which has this behaviour is the logistic curve or 'S' curve of the form;

$$f(t) = f(to) - \frac{f(to)}{1+Ae^{-kt}}$$

Where,

f(t) is the cost performance at time t (in years),

f(to) is the cost performance as of today,

A and k are parameters of the curve. (refer APPENDIX C)

Technological change in the fast growing telecommunication field can be pictured graphically by a

series of displaced trough shaped curves whose envelope is the 'S' curve mentioned previously. These intersecting curves represent the gradual displacement of old technologies by their successors. In figure 3.4 the curves of technologies I and II represents the case of well developed old technologies, versus the dotted curve of a new technology in the early stages of development. The company with foresight enough to steer its planning to the new technology will gain substantial advantage in its cost reducing measures.

3.1.5 Measuring Technology

Technological change as depicted by the 'S' curve may be measured in terms of an index; treating the 0th year ordinate as 1, the other ordinates of the future years may then be expressed in terms of the base year. This index will either positively or negatively influence the decision to defer the present technology being used.

In order to plot the 'S' curve, the individual technology curves need to be plotted first. This entails the drawing of two curves for capital cost and the operating cost per subscriber line per unit of distance. From the capital construction accounts of the outside plant equipment, the aggregate capital cost of a certain type of plant in a particular year is derived. This cost when divided by the quantity of lines installed will give the

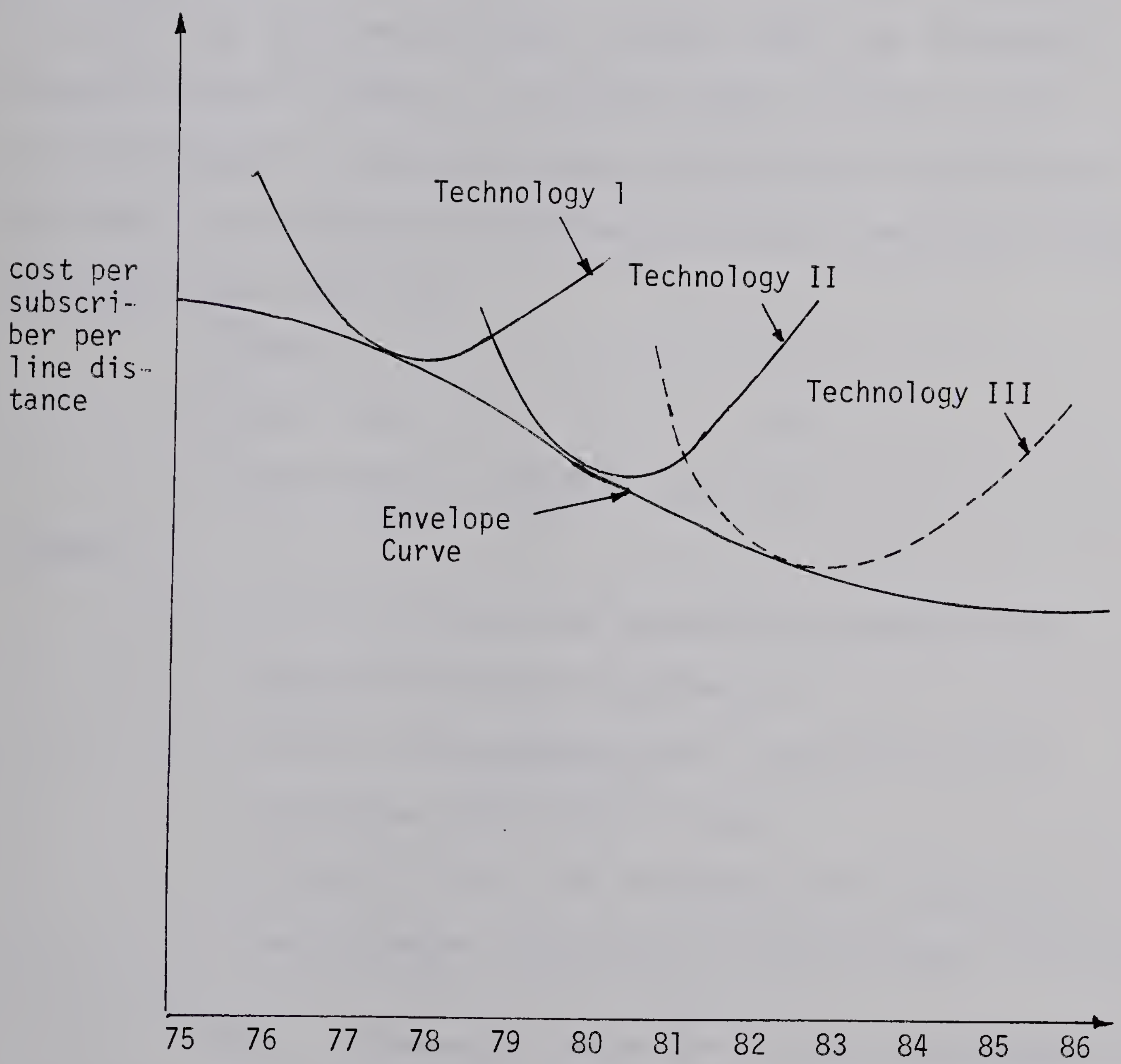


Figure 3.4 Technology Survivor Curves and the Envelope Curve

capital cost per line per unit of distance. In the case of operating cost, it is not realistic to find the figure for a particular vintage. However, if we assume that the operating cost of a certain item of plant is increasing with age at the rate of 'b' per year per dollar, then the following equations may be used to calculate the operating costs attributable to a certain class of plant in a particular vintage. For example if we consider three consecutive years, the equations will be:

$$\begin{array}{llllll} 1^{st} \text{ year} & x & & & = & T1 \\ 2^{nd} \text{ year} & (1+b)\,x\ + & Y & & = & T2 \\ 3^{rd} \text{ year} & (1+b)^2\,x\ + & (1+b)Y\ + & Z & = & T3 \end{array}$$

where,

T1, T2, T3 are the operating costs of the respective years considered.

'X' is the operating cost incurred on the surviving plant in 1st year.

'Y'and 'Z' are the operating cost incurred on the vintages installed in the 2nd and 3rd years.

Once a reasonable value for 'b' is established by the maintenance department, that value can be used and the above equations can be solved for the values of 'Y','Z' and so on. From this figure the operating cost per line per unit of distance is easily found.

3.1.6 Logistics Curve

In the logistic curve (normalized 'S' curve), in Figure 3.5:

$$f(t) = f(to)-f(to)/[1+A(EXP(-kt)]$$

dividing by f(to)

$$f(t)/f(to) = 1 - 1/[1+A.EXP(-kt)]$$

If we assume a constant improvement in the technological performance and assuming a 30 year time span, then;

$$TI(t+30)/TI(t) = (1-IT)**30 \quad ....(1)$$

where,

TI =ordinate of the normalized 'S' curve

TI(t) =ordinate of the 'S' curve in year 't'

TI(t+30) =ordinate of the 'S' curve in year 't+30'

IT =constant technological improvement factor.

From equation (1),

$$IT = 1-e^{\frac{\left[\ln\left\{\frac{TI(t+30)}{TI(t)}\right\}\right]}{30}}$$

This factor, IT, will be incorporated into, the interest rate factor, as shown in section 3.4.1.(a).

3.2 The Structure of The Cost Model in Relation to PNET

In order that the cost model performs the computation for the 'PNET' model, it has to be structured in a particular manner. Considering a specific technology, Figure 3.6 explains the situations under which the cost model will

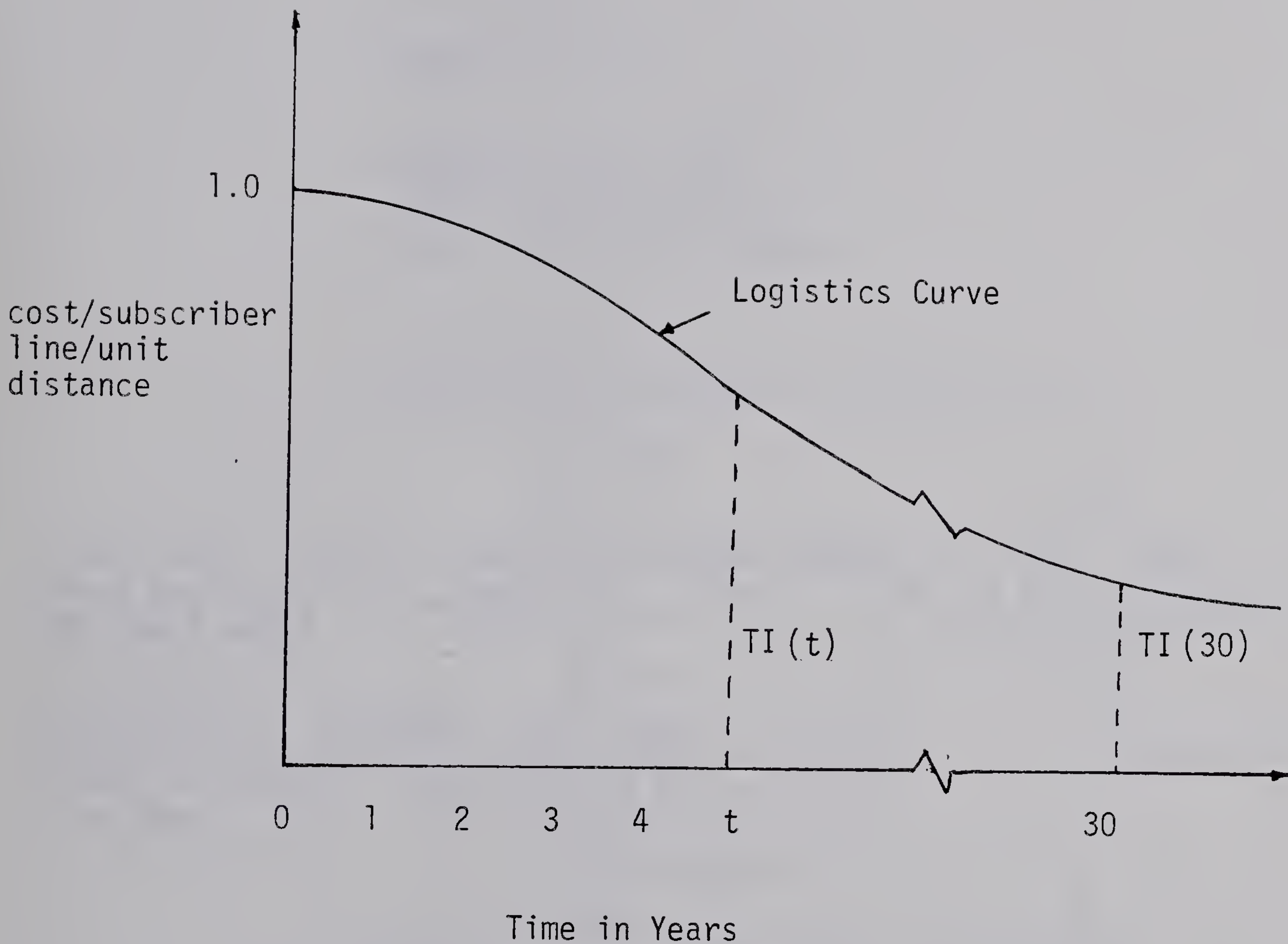


Figure 3.5 The Logistics Curve (Normalized to the Cost in Year Under Consideration)

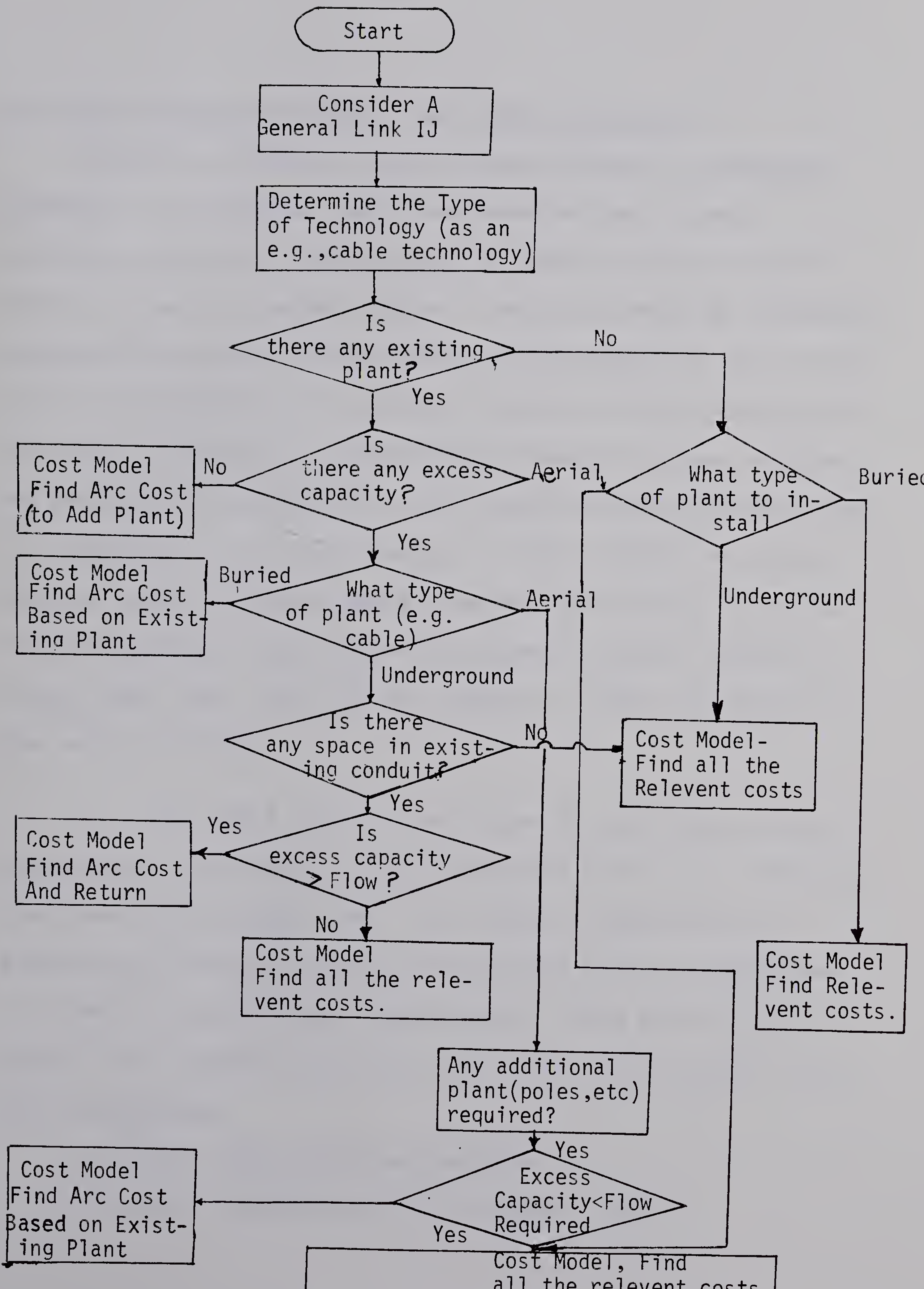


Figure 3.6 The Structure of the Cost Model In Relation to the PNET, Program

be required to do the computations for the 'PNET'model.

3.3 The Development of the Basic Cost Functions

Individual carrier companies use slightly different methods of developing their construction unit costs. Construction unit costs by type of plant forms the basic input to the cost model. Since a uniform system of measuring company performance is desirable or necessary at some stage, it is recommended that a uniform system for the development of costs be adopted. A company may develop its own program to convert its construction unit costs to the arc costs that is required by the PNET program. In this report an effort is made to build the cost model from the basic data. However, it is relatively easy for an individual carrier company to adopt their unit costs to the system in order to arrive at the unit arc cost.

The total cost of the plant is split into three components; (1) capital cost (installed cost), (2) operating cost, and (3) salvage cost. For capital budgeting and monitoring purposes a unit construction cost is desirable. In order to develop unit construction costs by type of plant, the capital cost is divided into the following basic cost components:

1. direct labor and its loadings,
2. direct material and its loadings, and

3. motor vehicle and tools capital cost, engineering overheads, contract work overhead and other overheads.

Although the operating cost could be split into the above basic components, the development of a unit cost for operating costs in the same manner as for capital cost is not practical. The system would require a tremendous amount of effort and additional paperwork on the part of all plant personnel and would be difficult to administer and monitor. Also the usefulness of operating costs to this degree of refinement is marginal in its contribution. Therefore, the operating cost is divided into only two basic components for each type of plant, by switching center area.

1. rearrangements or change (modifications), and,
2. ordinary repairs and maintenance.

These operating costs and any other costs in that category that are not covered are expressed as a percentage of the capital costs.

The direct labor item of the capital cost will be affected by such factors as:

1. seasonal differences
   - rainy weather and cold climate will influence the time taken to do a job;
2. geographic variations in a switching center
   - varying geographic conditions favors the decision of one type of plant in preference to another.

The salvage value and depreciation form a portion of the total cost and will be treated together in the analysis. The division of the total cost into its components is shown diagrammatically in Figure 3.7. The cost functions will be developed in reference to these components considering a general link i-j. Once the cost functions are developed for a specific technology, it is easily extended to cover other technologies.[20,21]

3.3.1 Direct Labor and its Loadings

Direct labor covers all direct labor costs for productive occupational hours charged directly to final accounts and to other accounts used for billing purposes. It covers the salaries and wages of occupational employees, first line supervisors and all other employees at the local plant administration level. These employees are identified by different craft types in this model. Figure 3.8 shows the components of the direct labor.

The loadings on direct labor are due to the indirect labor force and other associated tool expenses which are supplemental to the direct labor in the completion of the job. For convenience of costing, they are generally expressed as percentages of the direct labor cost. Figure 3.9 shows the components of the loadings applicable to direct labor.

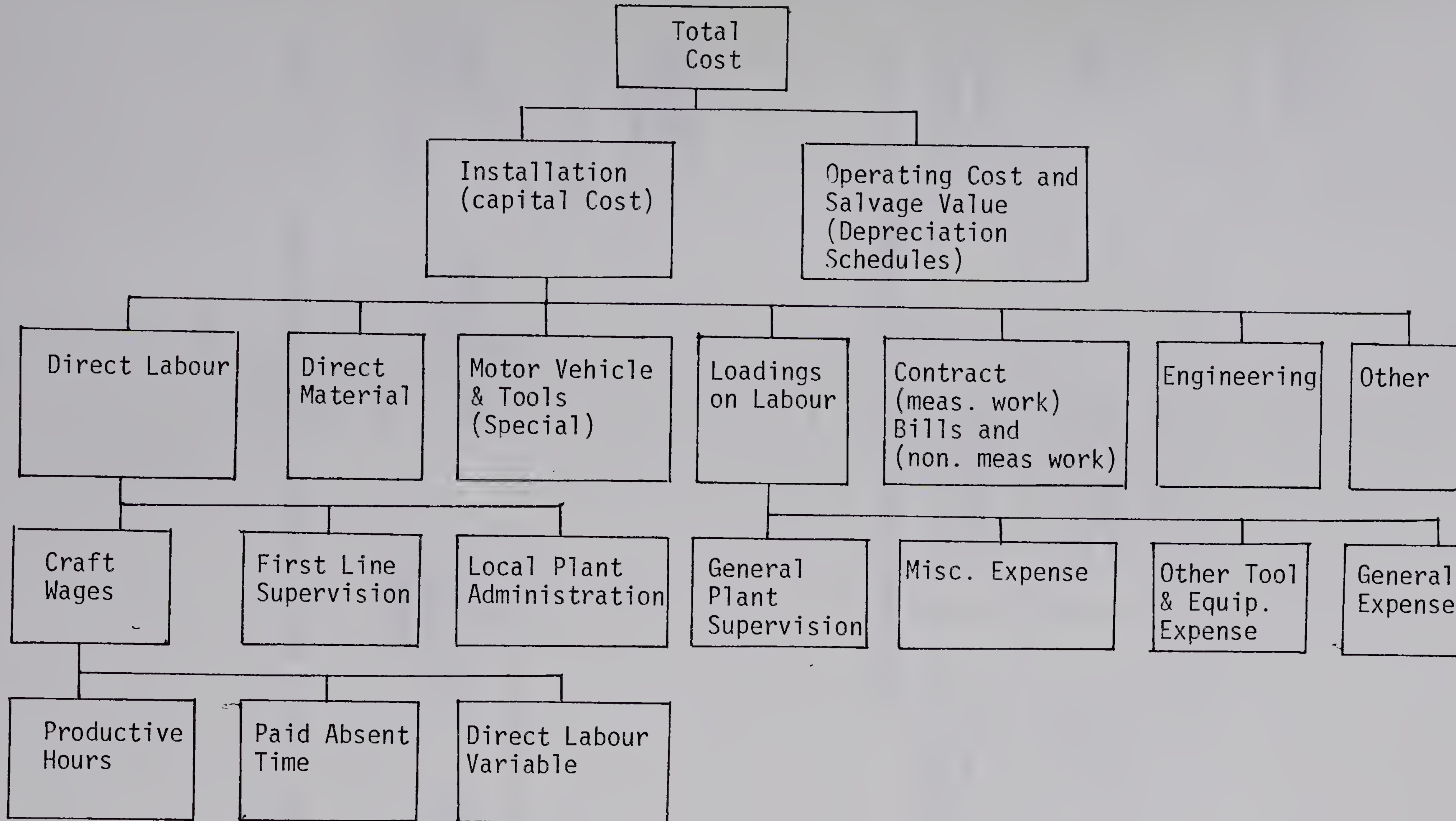


Figure 3.7 Components of Total Cost for Telecommunications Plant

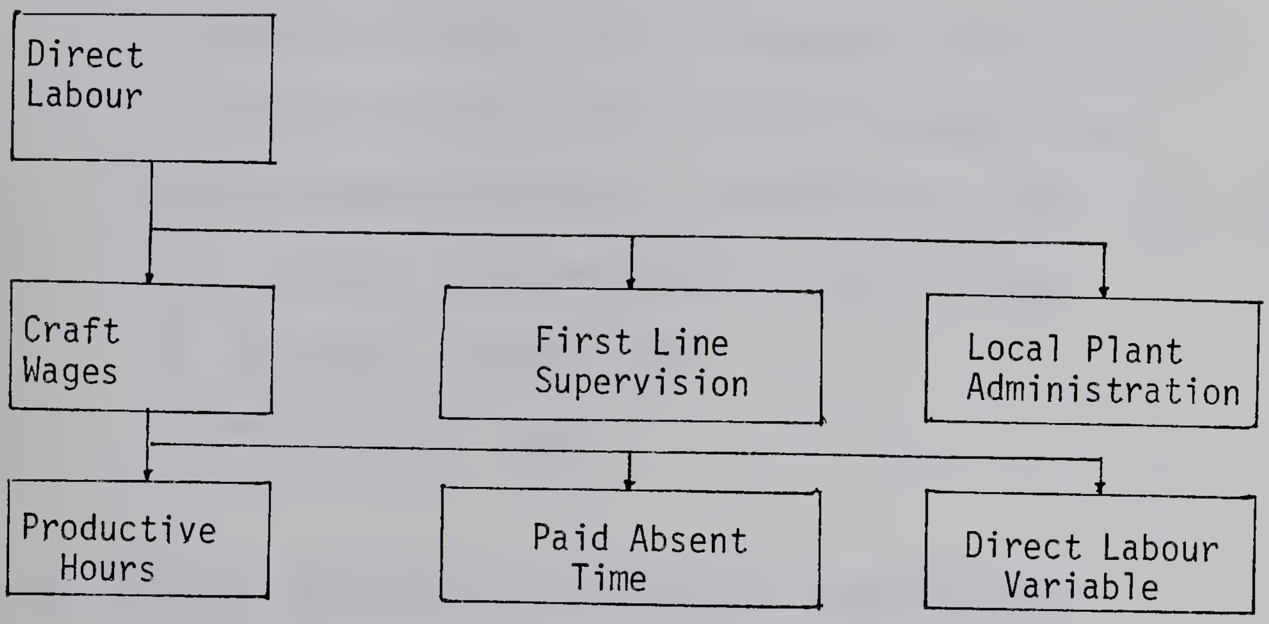


Figure 3.8 Components of the Direct Labour Cost

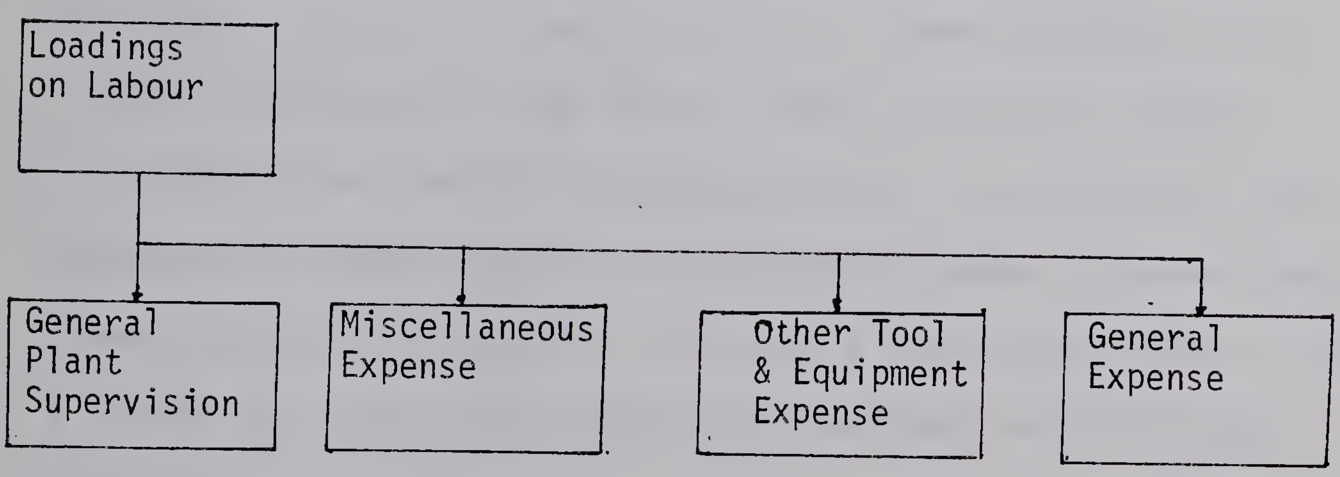


Figure 3.9 Components of the Loadings on the Direct Labour Cost

The total direct labor cost is discussed under the following sub-headings in order to include all the factors that influence the direct labor cost:

1. direct labor time by function performance,
2. direct labor hourly rate by craft type,
3. loadings on labor, (and direct labor cost model),
4. seasonal differences in labor rates,
5. learning curves, and
6. geographic area.

1. Direct Labor Time by Function Performance

The direct work content of a job (Function Performed) is usually estimated by various time study methods. This involves dividing operations into their basic elements, applying time factors to these elements and finally arriving at the total time for each function performed. The carrier companies have a reasonably good estimate of these basic direct labor times. (These basic times such as the time to install a pole, the time to place a meter of cable etc. should be checked periodically by job sampling techniques.)

For the general link i-j, the direct labor time by function performed is computed in the format shown in Table 3.1. If some of the functions are irrelevent to the link considered, then the corresponding time elements are set equal to zero.

Table 3.1 Direct Labour Time by Function Performed

Function Performed	Construction (C) in manhours	Install & Repair (R) in manhours	Removal (X) in manhours	Changes (M) in manhours	Others (O) in manhours	Total hours
Installing Poles	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{aa}
Laying Aerial Cables	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{bb}
Trenching	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{cc}
Laying Under-ground Cable	x_{41}	x_{42}	x_{43}	x_{44}	x_{45}	x_{dd}
Laying Under-ground Con-duits(+Manhole)	x_{51}	x_{52}	x_{53}	x_{54}	x_{55}	x_{ee}
Digging for buried cable	x_{61}	x_{62}	x_{63}	x_{64}	x_{65}	x_{ff}
Laying buried cable	x_{71}	x_{72}	x_{73}	x_{74}	x_{75}	x_{ee}
Installing loading coils etc.	x_{81}	x_{82}	x_{83}	x_{84}	x_{85}	x_{ff}

2. Direct Labor Hourly Rate by Craft Type

Direct labor costs are calculated in proportion to the productive hours of associated occupational employees, using a predetermined direct labor hourly rate. The direct labor hourly rate should represent occupational, first-line supervisory and local administration costs, the cost of paid absent time (vacation, sickness, etc.) premium payments (overtime, night differentials, etc.) and unclassified time. Direct labor hourly rates for plant personnel vary depending on the skill of the individual. Plant personnel are divided into groups representative of their duties, each group being designated by a letter :

Craft A -(line and cable placing forces)- This group also includes employees engaged as unskilled labor for digging and trenching etc.

Craft B -(cable splicing forces)- Employees who are primarily engaged in splicing or repairing aerial, underground, buried cables, e.g. cablemen, cablesplicers. This group also includes occasional employees engaged to assist in splicing work.

Craft C -(equipment installers)- Employees who are primarily engaged in installing, removing, accepting or rearranging central office equipment associated with outside plant facilities.

Craft D - Personnel involved in the inspection of contract work involving the construction, repair rearrangement and removal of outside plant facilities.

They are known as first line supervision.

Craft E - Mainly inspection personnel or local plant administration personnel.

The work force costs are calculated from the components shown in Table 3.2. The total manhours are obtained from the payroll information. The total direct manhours is multiplied by the productivity of the different craft type in order to arrive at the actual manhours for each craft type. The productivity consists of a combination of factors that will have to be estimated by the engineer in charge. The total cost column is divided by the actual direct man hours to arrive at the average direct labor rate by the craft type. The required elements in this matrix are filled with data from the past year, or the past period whichever is appropriate.

In Table 3.1, the productive assignable hours includes manhours resulting from construction, installation and repair, removal, and changes. The unassignable occupational hours consisting of holidays, vacations, sickness, personal absences and other unclassified hours are excluded from the productive hours and they are classified under the column of other manhours. When a contractor performs the functions described above, contract equivalent hours are to be derived by dividing the contractors bill by an appropriate loaded company rate.

Table 3.2 Direct Labour Rate by Crew Type

Craft Type	Regular Payroll $	Overtime $	Hiring/ Training $	Employee Termination $	Shift Premium $	Total Cost $	Total Manhours (hours)	Productivity	Direct Labour Rate ($/hr)
Craft A									DLR_A
Craft B									DLR_B
Craft C									DLR_C
Craft D									DLR_D
Craft E									DLR_E

If 'Xuv' denotes a general direct labor time associated with a function performed 'u' and type of work 'v' , in Table 3.1 [1,3], Xuv can be further split to take account of the percentage work contributed by different crafts. Note Table 3.3.[1,3]

Once the appropriate elements of the total direct labor cost in a general link i-j are determined, these values are linearly spread over the entire length of the link. This means that for some categories of jobs (e.g. installing poles) the direct labor costs are expressed on a unit linear distance basis (for simplifying the programming). However, for other categories of jobs (e.g. placing cables) the direct labor costs are computed on a unit distance basis from the beginning itself. These values when multiplied by the distance between the nodes i,j will give the value of the direct labor cost in the link i-j.

Using the above format, the direct labor cost can be computed for the different categories of jobs. As an example:

The direct labor cost for the installation of poles equals,

$$X_{aa}[P_{11}.DLR_A) + (P_{21}.DLR_B) + (P_{31}.DLR_C) +$$

$$(P_{41}.DLR_D) + (P_{51}.DLR_E)]$$

The direct labor cost for the laying of aerial cable

$$= X_{bb}[(P_{12}.DLR_A) + (P_{22}.DLR_B) + (P_{32}.DLR_C) +$$

$$(P_{42}.DLR_D) + (P_{52}.DLR_E)]$$

Table 3.3 Percentage Work Content by Craft Type

Craft	Poles	Aerial Cable/Coaxial	Trenching	Underground Cable/Coaxial	Conduits (& Manholes)	Digging	Buried Cable/Coaxial	Installing loading coils etc.
Craft A	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	P_{16}	P_{17}	P_{18}
Craft B	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{26}	P_{27}	P_{28}
Craft C	P_{31}	P_{32}	P_{33}	P_{34}	P_{35}	P_{36}	P_{37}	P_{38}
Craft D	P_{41}	P_{42}	P_{43}	P_{44}	P_{45}	P_{46}	P_{47}	P_{48}
Craft E	P_{51}	P_{52}	P_{53}	P_{54}	P_{55}	P_{56}	P_{57}	P_{58}

Similarly the direct labor cost for other items are developed. If the total cost of the direct labor, which is the sum of the above cost items, is denoted by 'C'; then ,

$$DL = C.dij$$

where,

DL = the direct labor

dij = the distance between the nodes i and j.

3. Loadings on Labor, Direct Labor Cost Model

Expenditures on indirect labor and other associated expenses are grouped under loadings on direct labor and are normally expressed as a percentage of direct labor. They are:

(a) general plant supervision = P(a)%

(b) tool and equipment expense = P(b)%

(c) fringe benefits and general expense = P(c)%

(d) plant miscelleneous expense = P(d)%

Therefore the total loadings on labor

$$= P = P(a) + P(b) + P(c) + P(d)$$

Since 'DL' is the direct labor cost described in the previous section, the total direct labor cost and the loadings are expressed mathematically by:

$DL(1+ P/100)$ per unit distance per unit of facility between the link i and j.

Therefore, Direct labor cost in the link i-j per unit of plant facility is equal to ;

DL (1 + P/100)dij

The above value when multiplied by the decision variable Xij will give the value of the direct labor cost plus loadings in the link ij. If the annual increase in the direct labor cost IDL is determined, it can be used to find the labor costs in subsequent years. The formula is modified to reflect the annual increase in direct labor. Hence to mathematically express:

Direct labor plus loadings becomes equal to;

$$DL(1+\frac{P}{100})d_{ij}\ X_{ij}[(1+\frac{IDL_n}{100})^n]$$

where,

Xij = the decision variable as determined by 'PNET'

IDL = the percentage increase in yearly direct labor

n = a suffix to indicate the period under consideration.

In that case inflation rate will have to be adjusted to avoid double counting and therefore was not included in that manner.

4. Seasonal Differences in Labor Rates.

Generally most of the construction work is seasonal (e.g. in Edmonton during the summer). If any work is done in the winter months, due to the climatic conditions prevalent, the standard time taken to do a job will likely change. In order to make a correction to the standard times used, the following modification is recommended.

Let Xuv denote a general element in the direct Labor time (Table 3.1). Then:

Standard time, Xuv = 1/100 [(Percentage work done during summer) x(Normal time in summer)+(Percentage work done in winter)x(Normal time in winter)].

Incorporating the productivity element into the model produces a typical productivity vs temperature graph which will look like the one shown in Figure 3.10.

If P(ref) denotes the productivity with reference to average year round temperature, and P(s) denotes the same for average summer temperature, and similarly P(w) denotes the productivity for average winter temperature, then:

Xuv =1/100 [(% work done in summer) x
(Normal time for Reference temp)}/P(s)
x Pref
+{ (% work done in winter)x
(Normal time for Reference temp)/P(w)
x P(ref)].

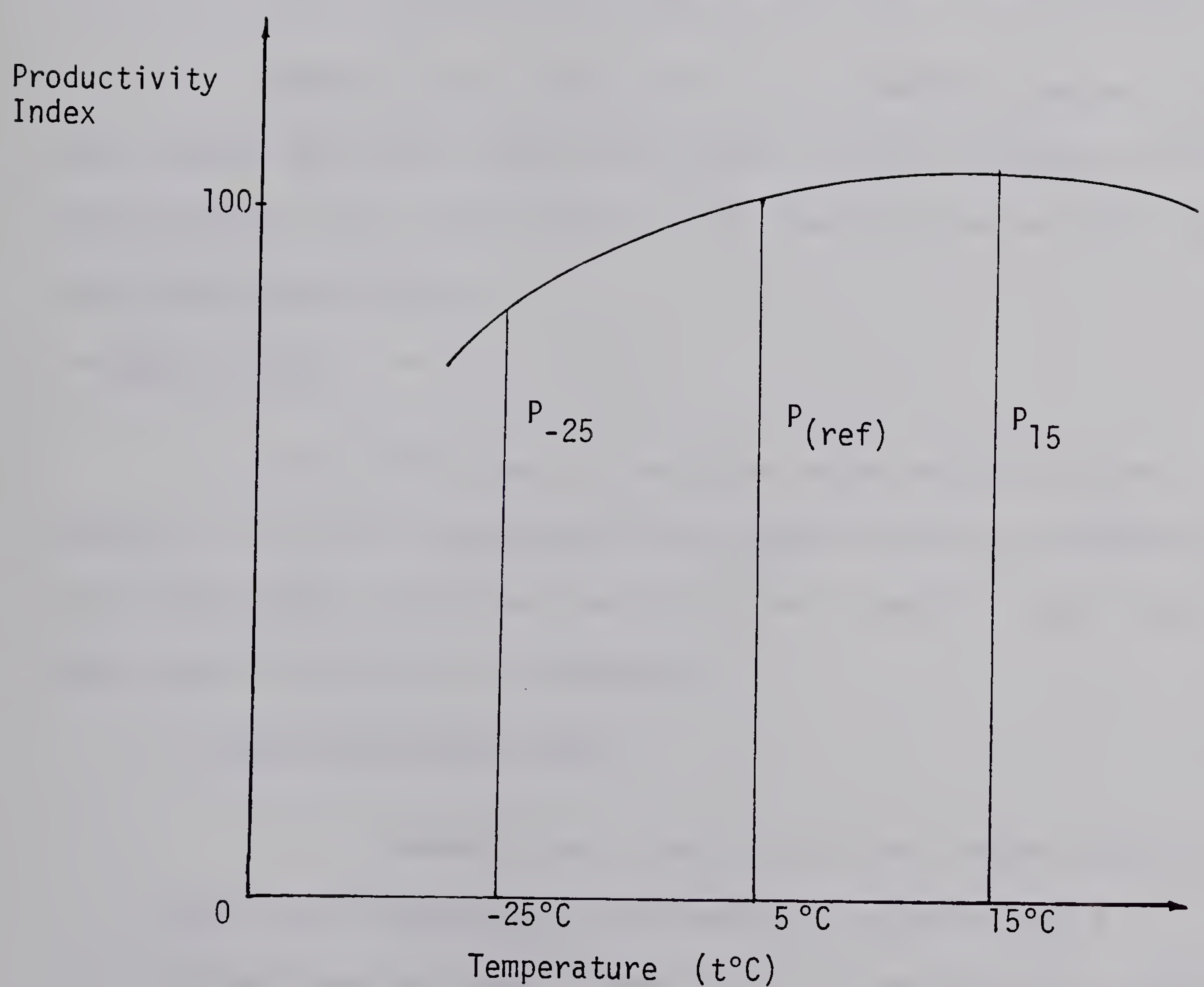


Figure 3.10 Productivity for Various Temperatures

where 'Normal time for the Reference Temperature' is the time taken to do the job at a particular reference temperature, assumed to be the average temperature for the year.

5. Learning Curves

An employee's efficiency is dependent upon the employee's experience in working with a new technology.

When all the employees are treated together the work units per hour index has been a good indicator of their performance. The terms used in the definition of this index are described below.

A. Work Units

Work units are a relative expression of the quantity of work represented by a given task or combination of tasks. They comprise 'measured work units ' and 'total work units' defined as follows:

1) Measured Work Units

Measured work units are the quantities of work units developed by counting selected work operations or plant items and then multiplying these counts by predetermined work unit factors. The factors relate to the system average work time in a past study period and include an allowance for work time on closely associated items which are not separately counted. They also include allowances for vocational

training time, travel and access time, job preparation time, etc.

2) <u>Total Work Units</u>

Total work units are measured work units plus an allowance of work units for unmeasured time.

B. <u>Work Units Per Hour</u>

Work units per hour is a comparative index of production based on the ratio of measured work units to measured hours. In reference to a past period, it shows the change that has taken place in work output as the combined result of changes in techniques and changes in operating efficiency. It shows the work output per hour expended.

This index, 'work units per hour' is easily obtained from accounting data and is projected into the future years. Assuming the 'work units per hour' index as 1 in year 0, the future indices can be found. The job times are multiplied by a factor which is the inverse of this index.

Therefore,

Standard time in year n

= (Standard time in year 0)/(work units per hour index in year n

6. Geographic Area

Varying soil conditions may be encountered in the same switching center area or in different switching center areas that makes one kind of job more difficult than the others. For example, hard rocky areas pose problems for trenching to lay underground cable. It is understood that the varying soil conditions directly affects the labor time. In order to account for these deviations, the switching center area is classified into the following categories of soils and they are identified by number codes. They are:

a) 1 - soft soil - suitable for normal operation,

b) 2 - hard rocky area - difficult for digging, trenching,

c) 3 - ravine or uneven area - poses problem for any aerial work,

d) 4 - paved areas - difficult for digging, trenching cost increases due to repaving, and

e) 5 - muskeg and swamp area - where work will be done in adverse conditions.

A difficulty rating matrix is constructed with the available information. Using 100 as the reference index for soft soil, the matrix will resemble the one shown in Table 3.4.

The switching center area is divided into zones and number codes will identify the difficulty factors applicable to that area under consideration.

Table 3.4 A Difficulty Rating According to Soil Conditions For the Placement of Telecommunications Plant

Function Performed	Code '1' Soft Soil	Code '2' Rocky Area	Code '3' Ravine Area	Code '4' Paved Area	Code '5' Swamps	Total Factor Being Denoted by '$D_{\ell k}$'
Installing Poles	100	D_{11}	D_{12}	D_{13}	D_{14}	πD_{1k}
Laying Aerial Cable	100	D_{21}	D_{22}	D_{23}	D_{24}	πD_{2k}
Trenching	100	D_{31}	D_{32}	D_{33}	D_{34}	πD_{3k}
Laying U.G. Cable	100	D_{41}	D_{42}	D_{43}	D_{44}	πD_{4k}
Laying U.G. Conduits	100	D_{51}	D_{52}	D_{53}	D_{54}	πD_{5k}
Digging	100	D_{61}	D_{62}	D_{63}	D_{64}	πD_{6k}
Laying Buried Cable	100	D_{71}	D_{72}	D_{73}	D_{74}	πD_{7k}
Installing Loading Coils	100	D_{81}	D_{82}	D_{83}	D_{84}	πD_{8k}

Note : π = Sum of the Product of the Difficulty Factors Relating to Different Codes

Total hours column Xaa,,Xbb... etc. in Table 3.1 will be prorated by the factor Dlk, depending on the type of job and whether the link i-j falls into any of the above categories of soil conditions.

3.3.2 Direct Material Cost

The material cost is divided into two components: (1) direct material cost, (2) indirect material cost.

The direct material costs are due to those materials which become a part of the transmission medium in the final subscriber loop and are involved in such a way that the material cost can be estimated. The indirect material costs are due to those materials which are critical to the operation but do not become a part of the transmission medium. These costs may include inventory carrying cost , ordering cost and shortage cost etc. These indirect material costs are normally expressed as a percentage of the direct material cost.

From an analysis standpoint, the direct material is subdivided into the following categories :

a) underground plant (includes cable, manholes, ducts, and loading coils etc.),

b) underground coaxial cable plant,

c) buried coaxial cable plant,

d) buried cable plant,

e) aerial cable plant, and

f) aerial coaxial cable plant.

The rules for the "resistance design" states that the total resistance of the subscriber loop under loaded or unloaded conditions is to be limited to 1300 ohms. This limit varies depending on the type of switching center equipment in use. The resistance limit implies that it is not always possible to use the thinnest gauge cable available, and in the case of long subscriber loops it becomes imperative to use loading and a combination of cables of varying gauges. In the case of composite gauges, the thinner cable is placed closer to the switching center. Normally subscriber loops (with combination of gauges) in excess of 5460 meters (18,000 feet) need loading.

Figure 3.11 shows the subscriber loop design chart. The limiting distance (resistance limit design) for using a 26 gauge cable in a non-loaded loop is approximately 4850 meters (16,000 feet). In the loaded environment, for instance the 24 gauge cable can handle a distance of approximately 7575 meters (25,000 ft.). Normally the routes must follow streets, which are for the most part rectangular in pattern, and the subscriber must be reached over the sum of the x-y coordinates with the switching center at the origin. The mean ratio of conductor route miles to airline miles based on the following mathematical development

SUBSCRIBER LOOP DESIGN CHART [Bell Telephone Co. of Canada]

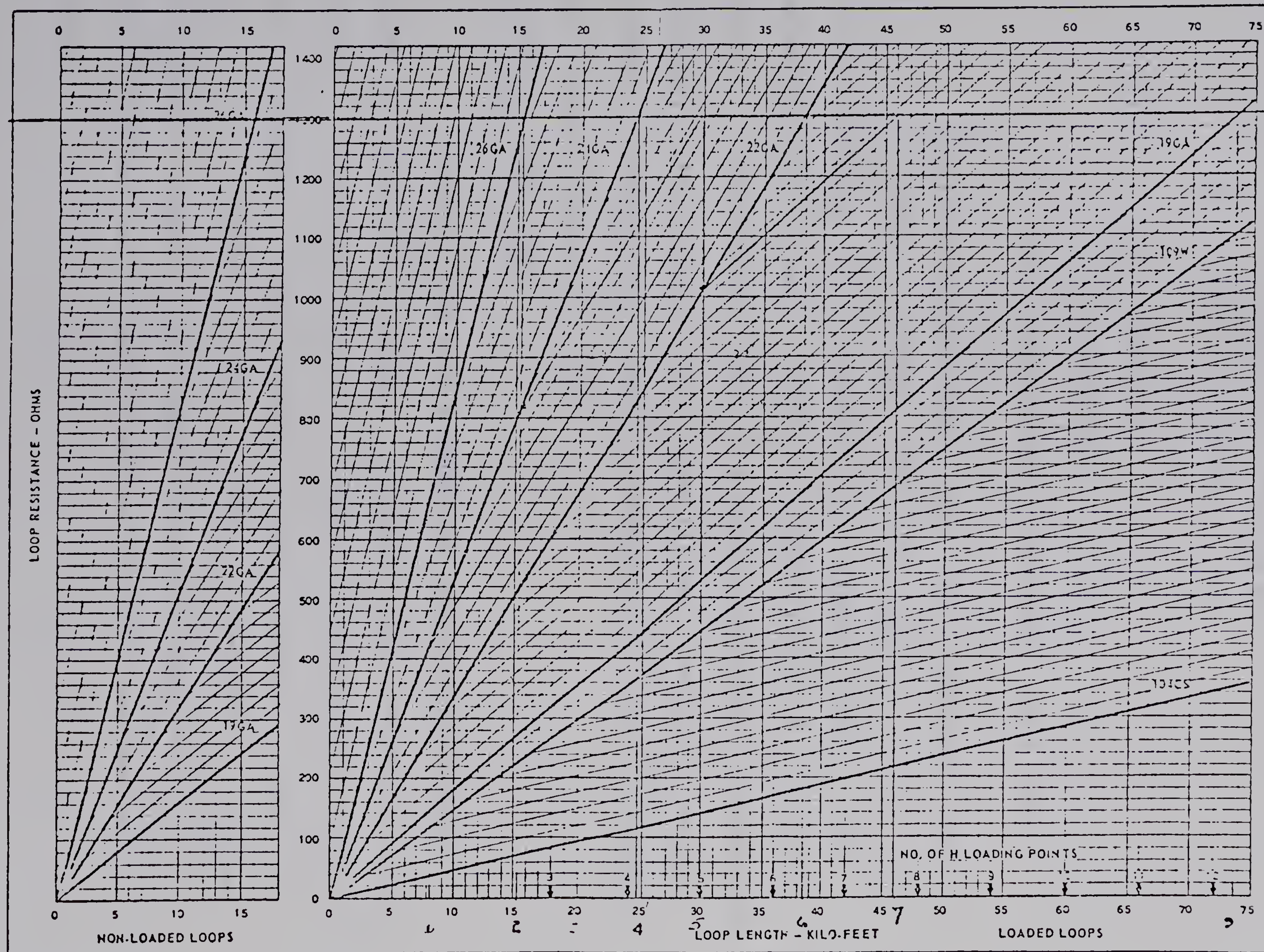


Figure 3.11 Subscriber Loop Design Chart

assuming a uniform arrangement would be:

$$\frac{R}{a} = \frac{\int_0^{\pi/2} \mathrm{Sin}\theta d\theta + \int_0^{\pi/2} \mathrm{Cos}\theta . d\theta}{\int_0^{\pi/2} . d\theta}$$

where R = route distance

a = airline distance

θ = angle between airline route and x axis.

The above ratio called airline ratio works out to be 1.27. Concentric contours (circles) are drawn with the switching center as the origin and a radius equal to the resistance limit length divided by this ratio, in order to arrive at a method of zoning the usage of various gauges. If an appropriate airline ratio specific to a carrier company is found by scientific sampling techniques, then that figure can be used instead of 1.27.

a) Underground cable

Normally the cable used for underground feeder routes is 3600 pair 24 gauge stalpeth cable. However, in any link ij , where the cable to be used is underground cable of cost C1 dollars, then the cost per unit length of cable is equal to C1/L where L is the standard length of the cable. The graph in Figure 3.12, shows the cable cost per unit length against the number of pairs of cable for various gauges.

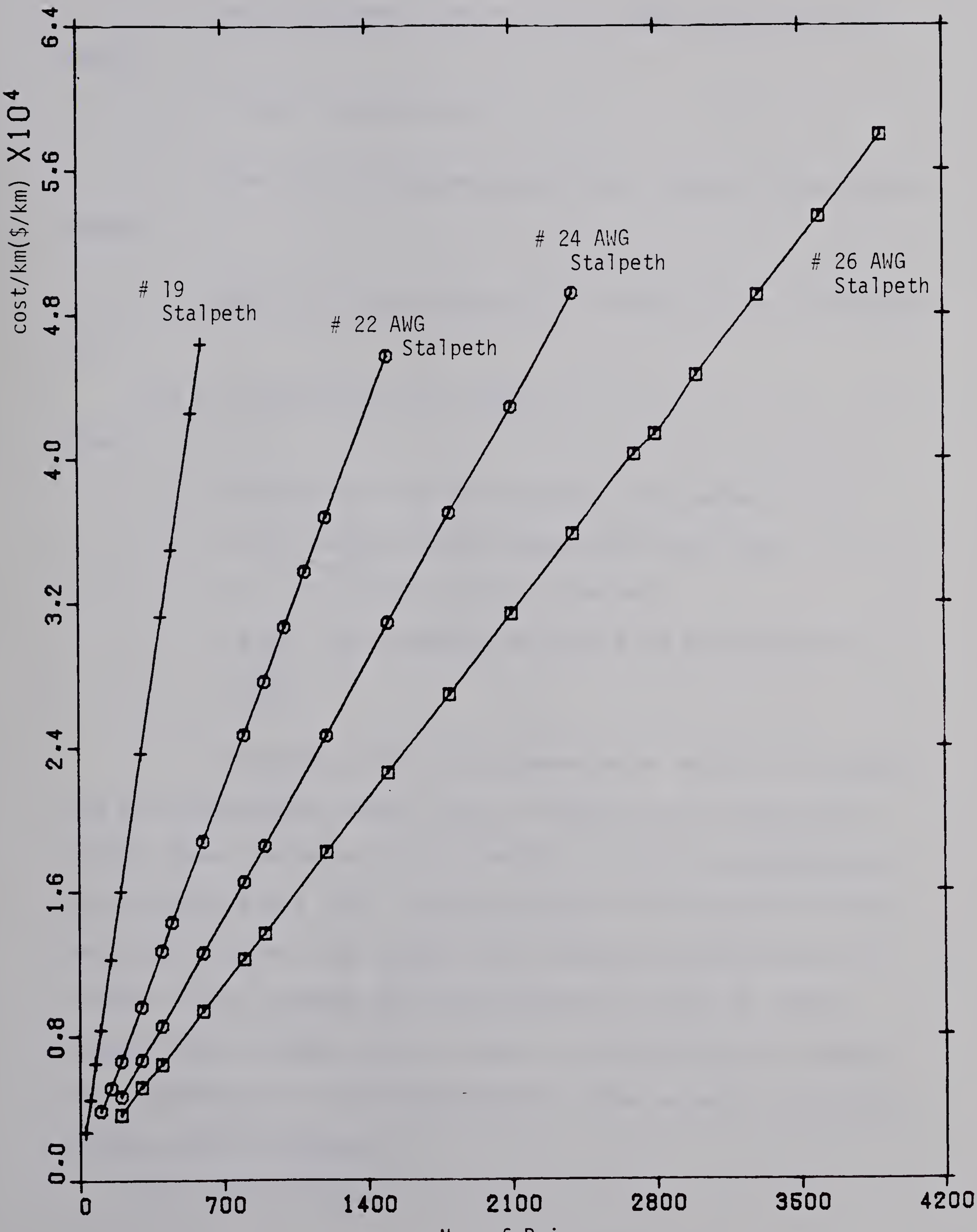


Figure 3.12 Cost per Unit Length of Cable Versus the Number of Pairs (Based on Published Price Lists for 1978)

Let UCC denote the cost per cable pair per foot, then

$$UCC = \$ (C1/L)/N$$

Then UCC is represented by the slope of the above curves.

The cost of the cable in the link ij will be equal to:

$$Xij [\{(100 UCC)/ F \} dij]$$

where,

dij = the distance between the nodes

UCC = the cost per cable pair per foot

F = the cable fill percentage

Xij = the decision variable as determined by PNET.

A maximum cable fill percentage of 80% is assumed and the forecasted demand will be updated to reflect the actual plant required in the model. A linear regression of cost of cable per unit distance versus the number of cable pairs is done and the slope and intercept of this line is stored in the program for the different types of cable. These stored values will be used in calculating the cable cost depending on the flow required. The general regression equation will resemble;

$$C1/L = ak + bk.Xij$$

where 'ak' and 'bk' are the intercept and slope respectively of the 'k' th type of cable.

b) Repeaters, Amplifiers and Load Coils

The voice repeaters, amplifiers and load coils are treated as terminal equipment and their weighted average costs are determined for the different sizes of cable plant, considering the frequency of usage.

If C(R), C(A) and C(L) represent the average costs of the repeaters, amplifiers, and load coils respectively that are installed in the circuit, then these costs are distributed over the entire length of the cable. Therefore, the cost function will be:

$$\left[\frac{100UCC}{F} \cdot d_{ij} + \frac{C(R) + C(A) + C(L)}{d_{ij}}\right] . X_{ij}$$

when, $\sum_{i=0}^{m} d_{i(i+1)} > d$ (m denotes the total number of nodes)

> 1.27xair line distance.

where 'd' is the cut off distance beyond which the use of voice repeaters, amplifiers and load coils are necessary. Otherwise the cost function will be:

$$\left[\frac{100UCC}{F.d_{ij}}\right] X_{ij}$$

when, $\sum_{i=0}^{m} d_{i(i+1)} < d$

The limiting distances are stored for each gauge of cable and 1.27 times the airline distance is compared with these figures , in order to find out whether loading is necessary and to include any relevent costs.

c) Underground Conduits

Normally the underground conduits are placed far in excess of the quantity required to meet the immediate demand. They are usually placed to handle ultimate demand. Figure 3.13 represents a typical cross section of a conduit, partly filled with cables.

If,

W = the number of way conduits

d(1),d(2) =the diameters of the conduit

C_2/L = the cost per meter of one conduit $\binom{\text{reference}}{\text{conduit}}$

F = the percentage fill allowed in any conduit

then, the cost of conduit in link ij is:

$$\frac{\left\{\dfrac{(C_2/L).w.d(2)^2}{F.d(1)^2}\right\} d_{ij}}{X_{ij}}$$

where,

d(1) = diameter of the conduit normally used,

and

d(2) = diameter of the conduit selected for use.

The cost per unit length (of different radii conduits) are plotted against the number of ways and is shown in Figure 3.14.

d) The Buried Cable

Let C3/L represent the cost of cable per meter and N is the number of pairs in the cable then, (Figure 3.15); the cost per unit length per pair of buried cable is:

UCC = (C3/L) /N

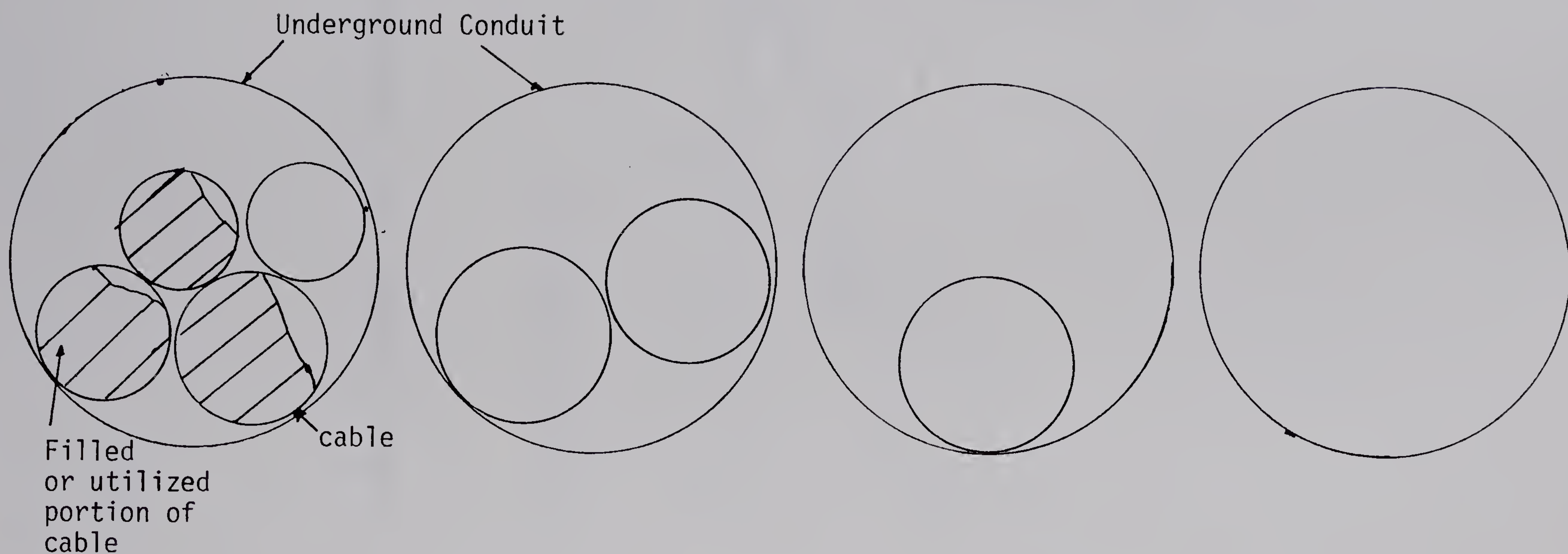


Figure 3.13 Cable Fill in a Four-Way Underground Conduit

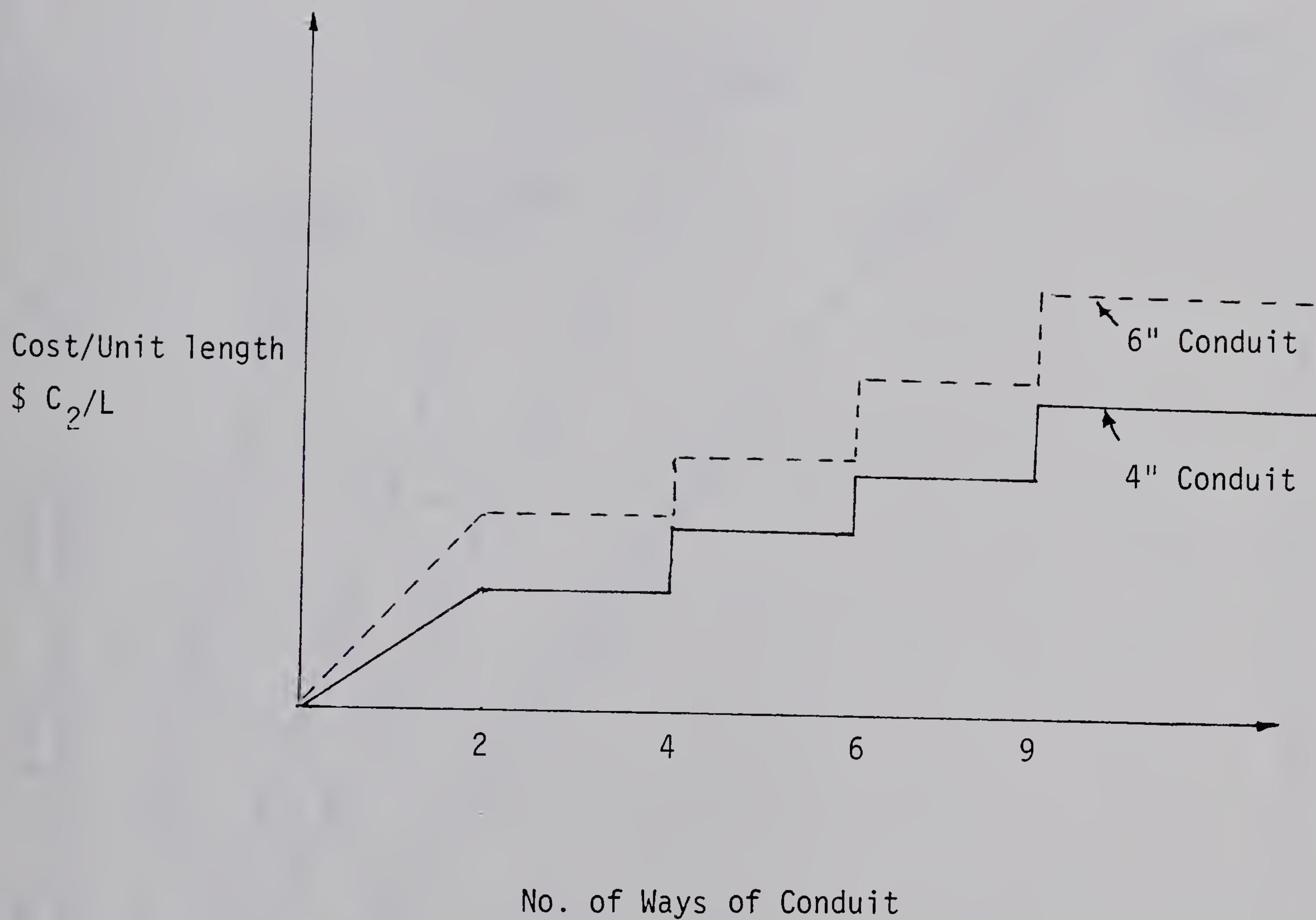


Figure 3.14 Conduit Price Vs. No. of Ways of Conduits

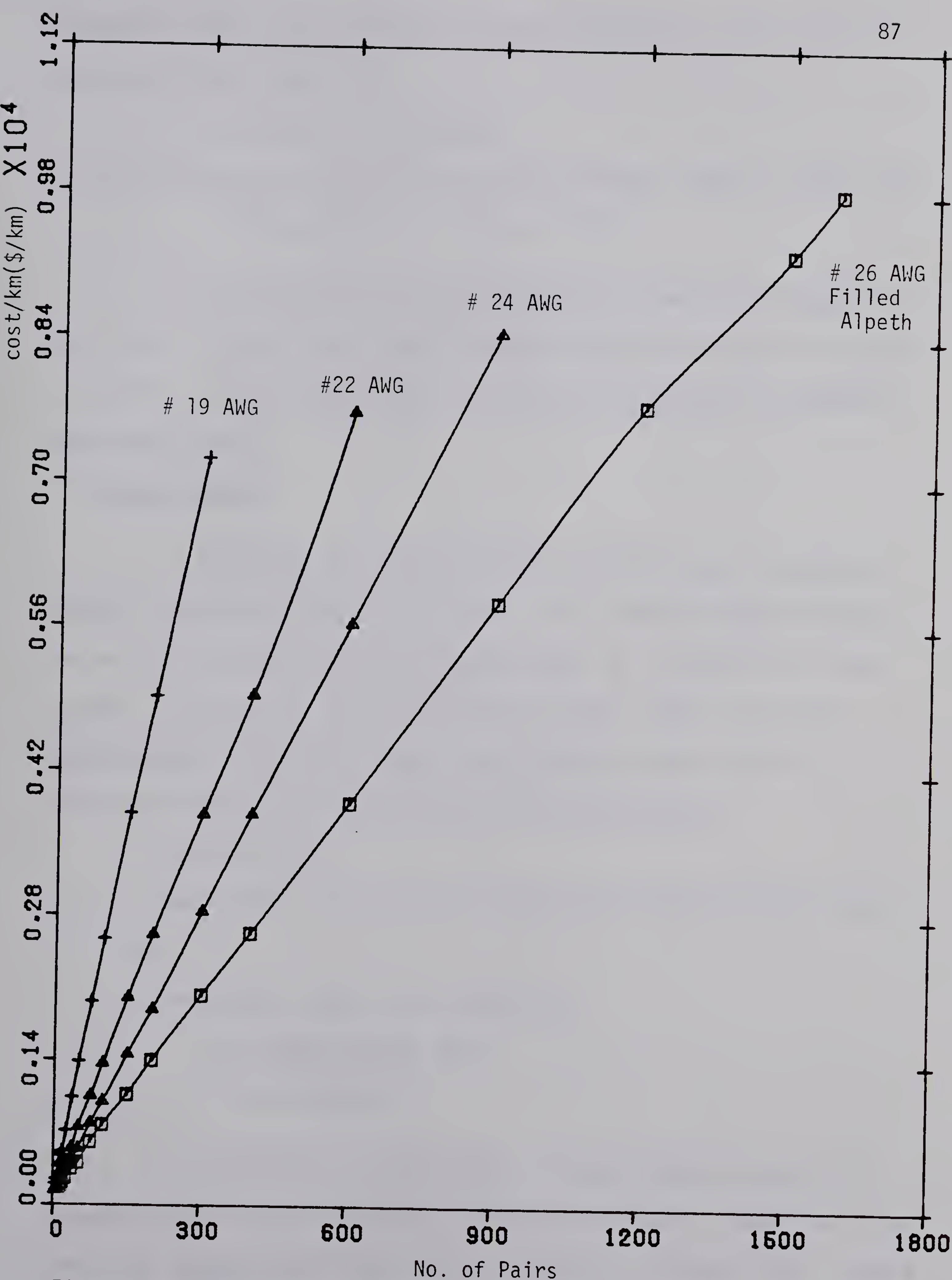


Figure 3.15 Cost per Unit Length of Buried Cable Versus the Number of Pairs (Based on Published Price Lists for 1978)

Therefore the cost per cable pair, assuming a percentage of fill of F% is equal to:

$$(UCC / F)\ 100.dij$$

which results in the cost of cable between nodes i and j as:

$$Xij\ [(UCC / F)\ 100 \cdot dij]$$

A straight line regression is done with respect to the cost of cable per unit distance and the number of pairs of cable . These regression values are utilized to compute the cable cost.

e) Aerial Cable

Normally the cable used is 50-600 pair straight alpeth (unfilled) 24 gauge cable. The average span between poles is 100 feet with a maximum span of 125 feet in some places . The poles are generally 35 feet high and cost approximately $300 per pole. The aerial cable cost is developed under the following classifications:

1. cable cost ;
2. pole cost -(sometimes shared with other utilities); and
3. auxillary pole line equipment
    a) cross arms, and
    b) terminals.

If (C4/L) is the cost of the cable per unit of length, and N is the number of pairs of cable, then the cost per unit length per cable pair is, UCC = $ (C4/L)/N , where N< 600. (Note Figure 3.16).

Let 'Cp' be the material cost of a pole and '(Σb) Cp/100' is the cost of the auxillary pole line equipment such as cross arms, terminals etc., where 'Σ p' is the overall percentage loadings of the above items on the material cost of the pole. In some cases the pole lines are shared with other utilities, and one of the elements of 'Σp' takes a negative value to account for this factor.

If 'r' is the number of poles between nodes I and J, then the cost of the poles between the nodes I & J ,

$$= r[Cp + \frac{(\Sigma p)Cp}{100}]$$

Therefore, cost per cable pair per unit distance (meter)

$$= \frac{r[Cp + \frac{(\Sigma p)Cp}{100}]}{N} \cdot \frac{1}{d_{ij}}$$

The total cost of pole lines in link ij,

$$= [\frac{C_4/L}{N} + \frac{r\{Cp+\frac{(\Sigma p)Cp}{100}\}}{N} \cdot \frac{1}{d_{ij}}]\ d_{ij}.X_{ij}$$

where Xij is the decision variable as determined by the PNET program.

The above procedure was repeated for other types of plant .

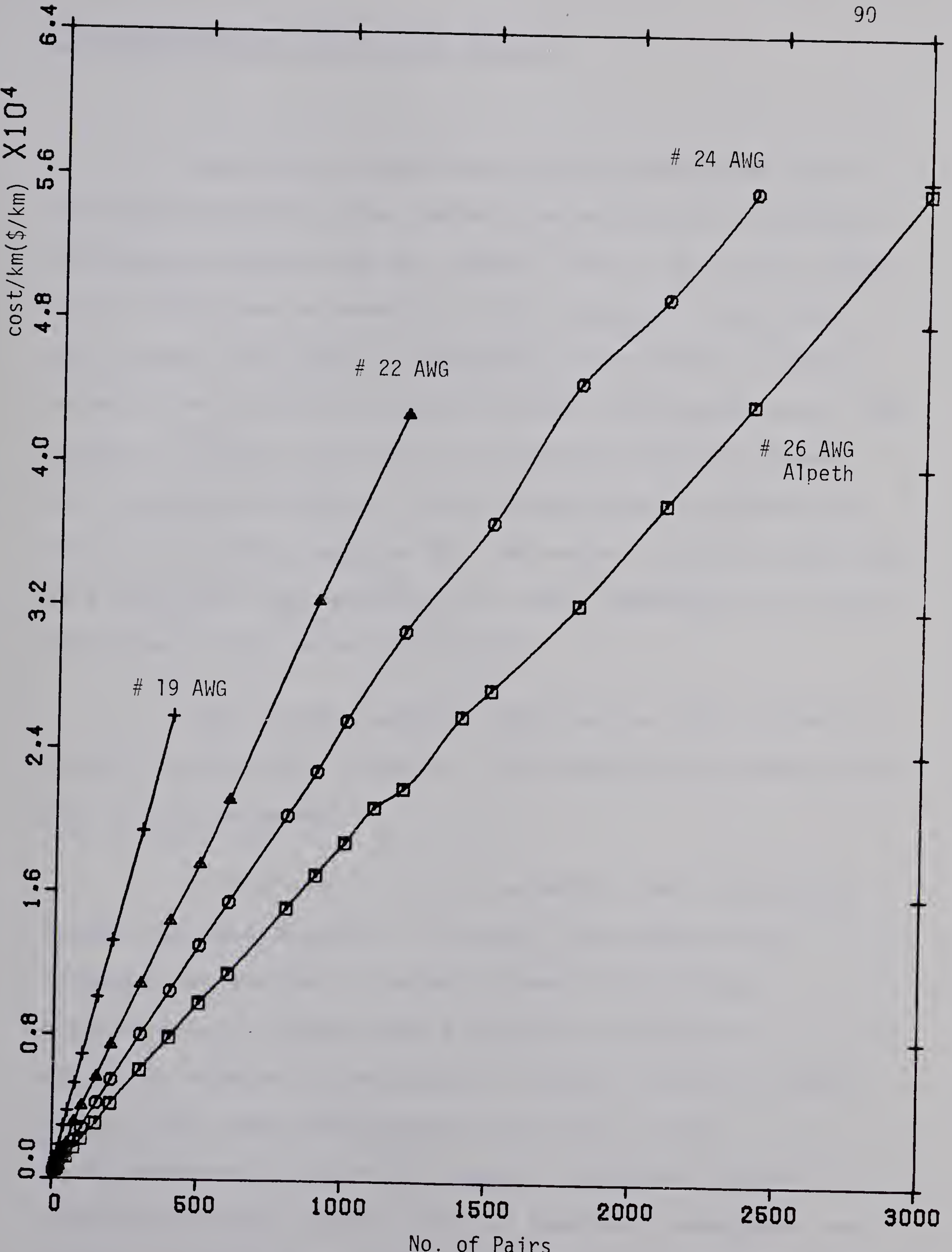


Figure 3.16 Cost per Unit Length of Aerial Cable Versus the Number of Pairs (Based on published Price Lists for 1978)

3.4 Depreciation and Salvage Values

Generally accepted accounting principles state that depreciation is the recovery of capital in a rational and uniform manner over the useful life of the plant. Under ideal conditions of constant dollar value, not only does this recover the capital investment in property in dollar amounts, but it also recovers the same purchasing power. The method of capital recovery that matches capital recovery with capital consumption while recognizing the dispersion about the average service life and which is still considered as a straight line method is the 'unit summation' or 'equal life group (ELG) method.[10,18,25]

Most of the carrier companies use this method in order to arrive at a value for the depreciation amount, for rate making purposes.

In the case of a pure economic study involving income tax considerations, however, the capital cost allowance to arrive at taxable income is the prime consideration. Capital cost allowance represents an allowable expense in arriving at taxable income and thus affects the cash disbursements for income taxes. Telecommunication plant (in Canada) is subject to the declining balance method, and the Canadian Government has chosen to group these capital assets by class(class 17)and to state the capital cost allowance rate (8%) that applies

to a specific class of assets.

The declining balance method as it implies, allows one to calculate the cost allowance by applying the capital cost allowance rate to the book value of the assets for the particular year in question.

In applying the depreciation rate the plant is grouped into categories as given below;

1. poles,
2. aerial cable,
3. ducts and vaults,
4. underground cable,
5. aerial coaxial cable,
6. underground coaxial cable,
7. buried coaxial cable,
8. buried cable, and
9. miscelleneous equipment.

If 'di' is the depreciation of the i th category of plant (on a unit basis) and 'Vi' is its estimated salvage value, then a capital tax factor (note derivation pp. 96-97) is computed for that plant and applied to the first cost and the salvage value. This factor takes into account all the effects of depreciation for tax purposes. In the case of surviving plant the initial cost is found from the book value.

3.4.1 The Total Cost Model

In designing a uniform system for the measurement of costs, there are three basic components that enter the total cost model.

4. An after-tax cash flow requirement(ATCFR). This requirement includes repayment of capital invested and an after-tax rate of return on the investment (The opportunity cost of capital). The required rate of return to meet the investors threshold of acceptability will be referred to as, (MARR) the minimum attractive rate of return.

5. An income tax requirement, and

6. An operating cost requirement.

Figure 3.17 is a simplified schematic of a corporate cash flow diagram.[22] This diagram specifically shows the major cost factors that contribute to the cost structure. The notations of the variables used in the development of the total cost model will be explained below. Their Fortran equivalents are given in brakets.[21]

ATCFR =after-tax cash flow requirement (ATCFR)

PEC = present equivalent cost (PEC)

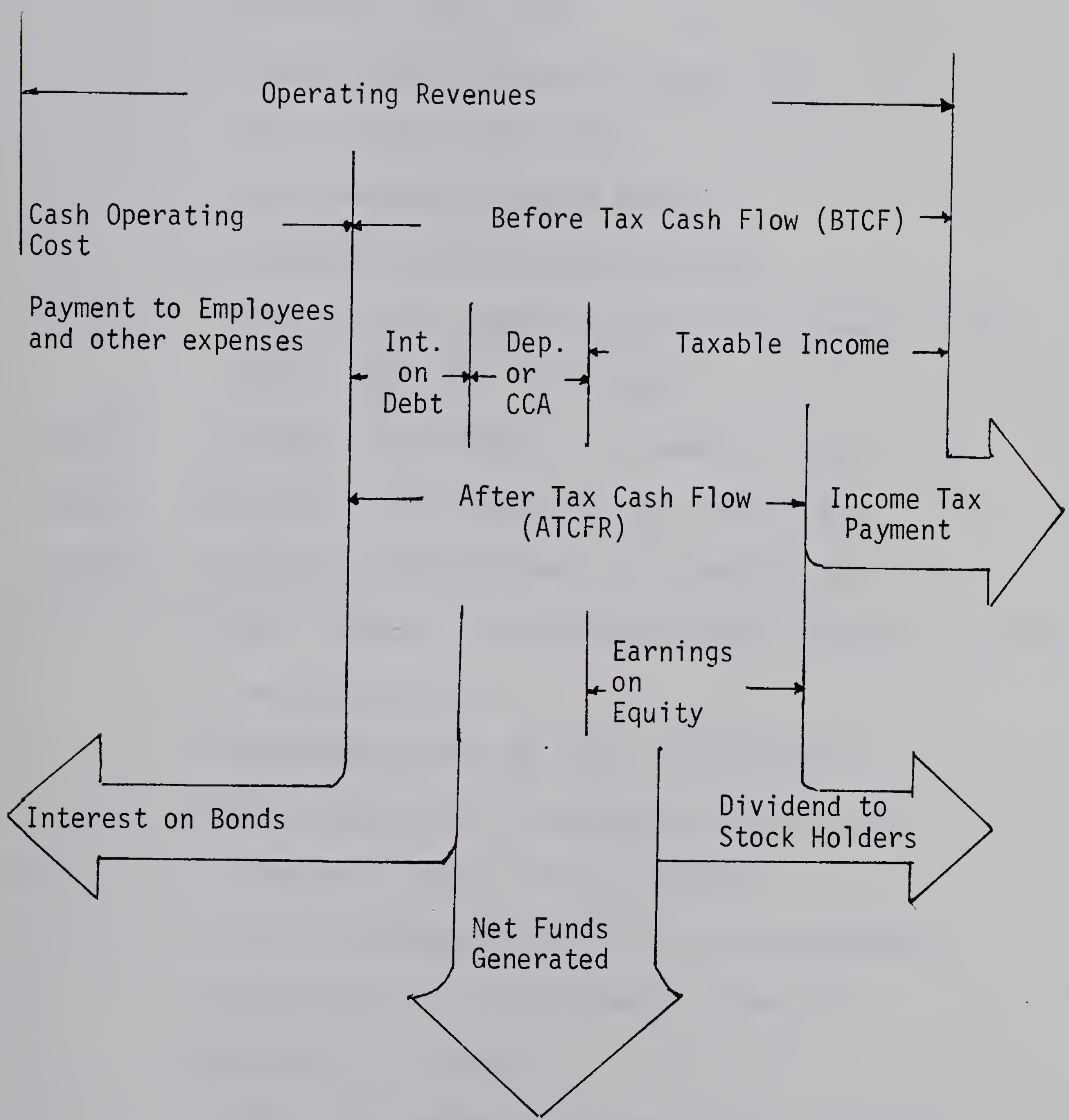


Figure 3.17 A Simplified Corporate Cash Flow Diagram [22]

PEM	=	present equivalent of operating costs (PEM)
B	=	first cost (the installed cost) (B)
V	=	salvage value (V)
n	=	number of periods in years (N)
N	=	life of the plant (NN)
t	=	the income tax rate (TT)
CCA	=	capital cost allowance (CCA)
PECCA	=	the present equivalent of the capital cost allowance (PED or PECCA)
$(a/p)_n^{ia}$	=	annual equivalent of a present sum
$(p/a)_n^{ia}$	=	present equivalent of an annual sum
$(p/f)_n^{ia}$	=	present equivalent of a future sum
rd	=	debt ratio(debt capital/(debt capital + equity capital)) (RD)
id	=	interest rate on debt capital(ID)
ie	=	interest rate on equity capital (IE)
ic	=	composite cost of capital(IC)
ia	=	minimum attractive rate of return(MARR)
it	=	technological improvement rate(IT)
if	=	inflation rate(IF)
d	=	declining balance depreciation rate(DRZ)
b	=	operating cost growth rate (b)
c	=	first cash flow in a geometric series of discrete cash flows
CTF	=	capital tax factor(CTF)
PPEF	=	partial present equivalent of a future sum (PPEF)
$(p/c)_n^{ia}$	=	present equivalent of geometric series

(a) Minimum Attractive Rate of Return

The effect of inflation on debt capital is assumed to be zero. The equity capital is fully responsive to inflation. Similarly the technological improvement on cost performance directly affects the equity capital, whereas the debt capital is unaffected by any change.

Hence, the cost of composite capital is a weighted average cost of capital based on the percentage of debt and equity in the capital structure:

$$i_c = (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + r_d.i_d \qquad (1)$$

The minimum attractive rate of return, MARR, is

$$MARR = i_a = i_c - t.r_d.i_d \qquad (2)$$

The component '$t.r_d.i_d$' is known as the tax shelter. Those carrier companies that do not pay any tax will have this term equal to 0 in equation (2). Combining equations (1) and (2)

$$\begin{aligned} i_a &= (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + r_d i_d - t.r_d.i_d \\ &= (1-r_d)[(1+i_e)(1+i_f)(1-i_t) - 1] + (1-t)r_d.i_d \qquad (3) \end{aligned}$$

This value of 'i_a' will be used in discounting the cash flow streams.

(b) Capital Tax Factor

If d= CCA rate, (declining balance method)

t = tax rate,

i = MARR, and

n = year:

then the installation of a depreciable asset for cost 'B' results in a series of tax credits equal to B.t.d in the first year, B.t.d.(1-d) in the second year, and so on B.t.d.(1-d)**n-1 in the nth year.

The present equivalent cost, after subtracting these series of tax credits is equal to :

$$PEC = B - \frac{B.t.d}{(1+i)} - B.t.d\frac{(1-d)}{(1+i)^2} \ldots\ldots - B.t.d.\frac{(1-d)^{n-1}}{(1+i)^n}$$

Therefore,

$$(1-d)(PEC - B) = -B.t.d[\frac{(1-d)}{(1+i)} + \frac{(1-d)^2}{(1+i)^2} + \ldots\ldots + \frac{(1-d)^n}{(1+i)^n}]$$

A geometric series is convergent with sum Sn = a/(1-r), if modulus of r is less than 1 , and n is very large, where 'a' is its first term and 'r' is its common ratio.

Therefore,

$$(1-d)(PEC - B) = -B.t.d \left[\frac{(1-d)/(1+i)}{1 - (1-d)/(1+i)}\right]$$

$$= - B.t.d(1-d)/(i+d)$$

$$PEC = B (1 - t.d/(i+d))$$

The factor ,(1 - t.d/(i+d)), is called the capital tax factor.

Assuming the books of the carrier company are open, the capital tax factor by class of plant is found ;

$$CTF = 1 - \frac{t.d}{(i_a+d)} \text{ ------------ } (4)$$

This factor when multiplied by the first cost of the plant (B) or the net salvage (V) in any given year will combine the effect of future tax savings on depreciable assets , and gives the after-tax cash flow of the plant.

(c) Present Equivalent of Maintenance

When the operating costs increase at a rate of b, with the age of plant:

Case 1 when b>IA;

$X=(1+b)/(1+IA)-1$

$$(p/c)_n^{ia} = [1/(1+IA)] \, (f/a)_n^X \text{ -----------} (5a)$$

Case 2 when b=IA

$X=0$

$$(p/c)_n^{ia} = n/(1+IA) \text{ --------------------- } (5b)$$

Case 3 when b is less than IA

$X=(1+IA)/(1+b)-1$

$$(p/c)_n^{ia} = [\ 1/(1+b)\ ] \, (p/a)_n^X \text{ ----------} (5c)$$

The maintenance cost in any given year when multiplied by one of the above proper factors will be brought to the present day dollar amounts. This factor is used extensively in calculating the present equivalent of maintenance cost (PEM).

(d) Total Cost Model

The present equivalent cost of an investment is given by;

$$PEC = PEM + \frac{[B - V(p/f)_n^i a - t(PECCA)]}{(1-t)}$$

Introducing the CTF factor given by equation (4), the above equation reduces to,

$$PEC = PEM + \frac{[B.CTF - V.CTF.(p/f)_n^i a]}{(1-t)}$$

This equation is used for every arc of the plant considered in the network. All the factors in the above equation will vary depending on the type of plant considered in the arc , the period under consideration, the estimated life of the plant, the operating cost attributable to each class of plant and whether it is an existing plant or a plant to be newly installed.

4. TESTING THE MODEL

Testing the model represents a joint effort between the writer and Vijayanandan[27]. The model was tested with a hypothetical problem on an Amdahl 470V/6 machine, at the University of Alberta computer installation.

The integral optimization model comprising the data bank, the input conversion system, master control unit (consisting of computer programs capacitate, update 1, update 2 and PNET), the output conversion system developed at the University of Alberta[27] along with the cost model was tested with the hypothetical problem in order to gather some valuable information before implementation.

4.1 Test Problem

The hypothetical problem used for the test was developed after a careful study of several switching center areas in the city of Edmonton, Alberta. Hence it represents a simulated version of the actual problem and was used to test the practical capabilities of the model. The use of a hypothetical problem enabled modifying the input data to test the model for the several different situations that are encountered in practice.

A map of the area used as the test problem is shown in Figure 4.1. The diagram shows locations of the various nodes in the network, both existing and alternative. The switching center(S), manholes(M) and the access terminals(T) form the different categories of nodes. The grid system used to descibe the network was one with a scale of 5metres/unit. But, any convenient system can be chosen in practice. Table 4.1 shows the coordinates of all the nodal points on the cartesian grid system chosen. This information is useful in locating the nodes in the physical network and relating the program output to physical facilities. A code consisting of a number followed by a letter is used to denote a node. The letter in the codes used in defining the nodes signifies the type of plant that is used at the node (e.g. switching center, manhole, access terminal).

The forecast information is shown in Table 4.2. To allow for possible bad lines within a cable and to account for errors in the forecast, a maximum permissible cable fill of 80% was used to obtain the number of lines required to satisfy the demand at each point. The map of Figure 4.1, the demand data and a percentage fill of 80% were used as the basis for developing the network information shown in Table 4.3. Note that in Table 4.3 all the arcs emanating from a node are placed together. This arrangement is necessary for the functioning of the optimization program.

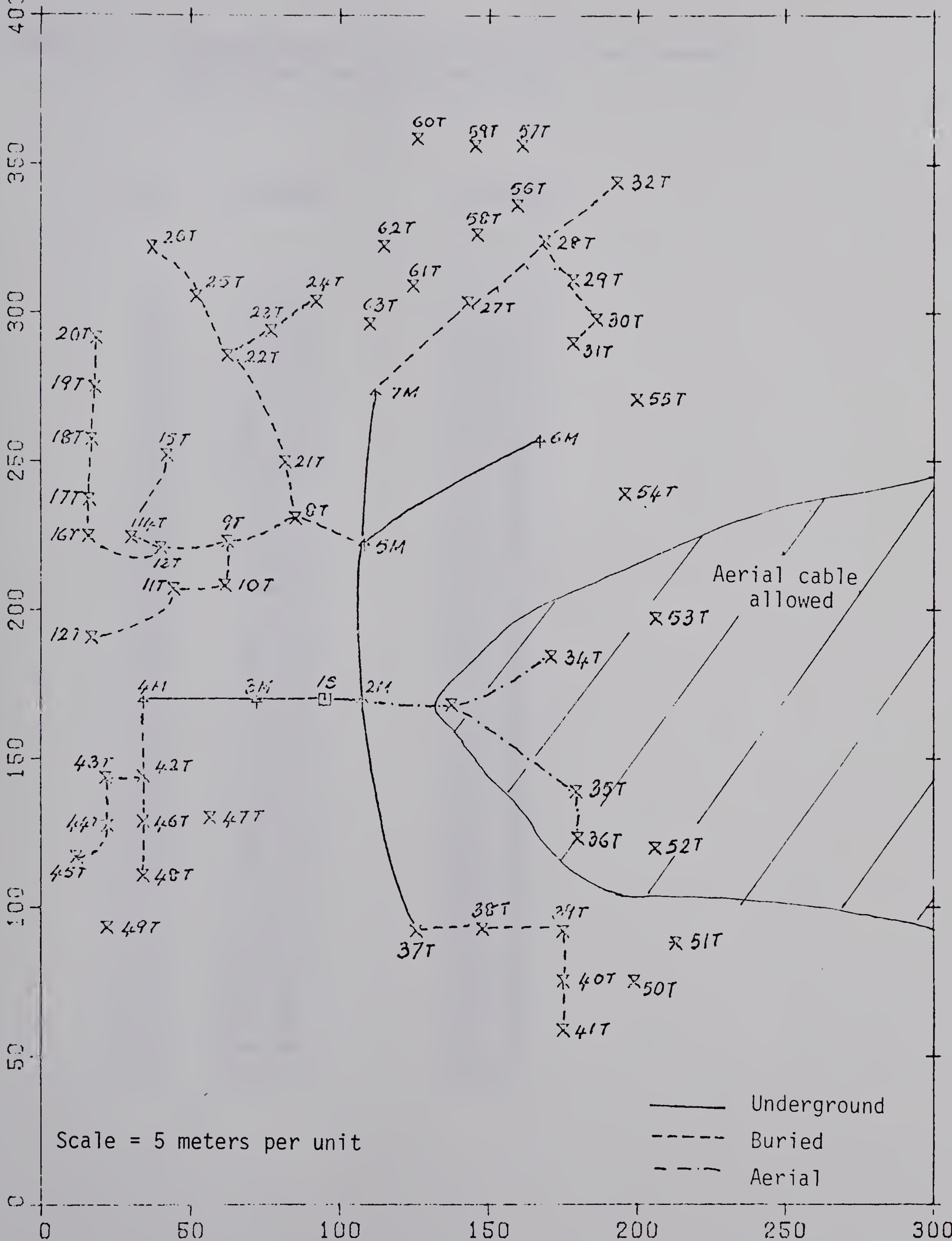


Figure 4.1 Map of the Test Area (Switching Center XYZ) Showing Existing Plant

Table 4.1 Co-ordinates of the Nodes in the Network
(Switching Center Area XYZ)

NODE	X-COORD	Y-COORD
1S	95.00	170.00
2M	107.50	169.00
3M	72.00	169.00
4M	34.00	169.00
5M	108.00	221.80
6M	167.10	256.50
7M	111.80	272.50
8T	85.00	231.00
9T	62.10	223.10
10T	61.30	208.30
11T	44.20	207.10
12T	16.80	190.70
13T	30.00	224.50
14T	16.10	237.20
15T	42.00	252.00
16T	15.80	225.00
17T	16.10	237.20
18T	16.90	257.40
19T	17.80	275.10
20T	18.40	291.50
21T	81.60	249.80
22T	62.10	285.70
23T	76.80	294.00
24T	92.00	303.90
25T	51.80	305.60
26T	40.00	220.90
27T	143.00	303.30
28T	168.90	324.00
29T	178.40	310.90
30T	186.30	297.70
31T	178.40	289.70
32T	193.10	343.80

Table 4.1 Co-ordinates of the Nodes in the Network (contd.)
(Switching Center Area XYZ)

NODE	X-COORD	Y-COORD
33T	137.60	168.10
34T	171.00	184.30
35T	179.40	139.00
36T	180.00	123.30
37T	125.70	92.00
38T	148.00	92.70
39T	175.00	91.90
40T	175.00	75.20
41T	175.00	58.80
42T	34.00	144.20
43T	21.50	143.70
44T	22.00	127.50
45T	11.80	117.00
46T	34.00	129.00
47T	56.40	130.20
48T	34.00	110.80
49T	22.00	93.30
50T	199.00	75.10
51T	213.10	88.00
52T	206.00	120.00
53T	206.10	197.20
54T	195.80	239.00
55T	199.80	270.80
56T	159.50	336.10
57T	161.20	356.20
58T	146.00	326.20
59T	145.40	356.10
60T	126.00	358.50
61T	124.50	309.00
62T	114.70	322.30
63T	110.00	296.20

Table 4.2 Forecast Information for Switching Center XYZ (in number of lines)

NODE	PERIOD1	PERIOD2	PERIOD3	PERIOD4
8T	55	0	0	0
9T	239	0	0	0
10T	21	0	0	0
11T	4	0	0	0
12T	19	0	0	0
13T	11	0	0	0
14T	11	3	7	0
15T	11	4	0	0
16T	79	39	39	239
17T	19	0	11	0
18T	19	0	0	0
19T	11	0	0	0
20T	79	0	0	95
21T	29	0	0	0
22T	32	0	0	0
23T	18	0	0	0
24T	7	0	0	0
25T	11	0	0	0
26T	11	0	0	127
27T	11	7	0	0
28T	15	7	7	0
29T	7	3	1	0
30T	4	2	4	67
31T	7	3	3	2
32T	39	7	7	103
33T	79	39	39	0
34T	39	39	0	0
35T	56	0	0	0
36T	19	0	0	0
37T	33	0	0	0
38T	17	3	0	0
39T	11	4	0	0

Table 4.2 Forecast Information for Switching Center XYZ
(in number of lines) (contd.)

NODE	PERIOD1	PERIOD2	PERIOD3	PERIOD4
40T	4	2	2	2
41T	19	3	3	211
42T	17	0	0	0
43T	7	3	0	0
44T	4	0	0	0
45T	11	3	3	299
46T	11	0	0	0
47T	19	7	3	0
48T	3	3	0	0
49T	11	4	3	3
50T	4	0	0	4
51T	7	7	3	27
52T	0	0	39	7
53T	13	7	7	15
54T	31	7	7	7
55T	7	7	7	0
56T	4	3	0	0
57T	7	3	3	0
58T	7	7	3	0
59T	3	5	8	2
60T	0	1	2	7
61T	11	11	7	4
62T	0	239	0	79
63T	3	3	3	3

Table 4.3 Network Data - Input to the Input Conversion System

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
1S	2M	1111	9400	1254	100	77.23	0.0	3
1S	3M	1111	3600	98	100	123.67	0.0	3
2M	5M	1111	7200	898	100	300.59	62.70	5
2M	33T	1111	1200	246	100	167.29	62.70	3
2M	37T	1111	1000	110	100	513.30	62.70	1
3M	4M	1111	3600	98	100	242.25	115.11	2
4M	12T	2151	0	0	100	173.86	305.04	0
4M	42T	1131	1800	98	100	166.40	305.04	0
5M	6M	1111	2400	0	100	453.71	267.03	2
5M	7M	1111	2400	111	100	254.61	267.03	3
5M	8T	1131	2400	787	100	124.26	267.03	0
6M	55T	2151	0	0	100	197.95	563.04	0
6M	54T	2151	0	0	100	191.28	563.04	0
7M	27T	1131	600	111	100	264.23	519.34	0
7M	63T	2151	0	0	100	159.20	519.34	0
8T	21T	1131	1200	104	400	108.18	309.07	0
8T	9T	1131	1200	683	400	158.50	309.07	0
8T	00							
70	0	0	0					
9T	10T	1131	200	58	400	98.14	312.33	0
9T	13T	1131	600	325	400	178.07	312.33	0
9T	00							
300	0	0	0					
10T	11T	1131	100	31	400	92.33	255.08	0
10T	00							
27	0	0	0					
11T	12T	1131	50	25	400	182.41	314.53	0
11T	00							
6	0	0	0					
12T	00							
25	0	0	0					
13T	14T	1131	50	30	400	124.69	424.12	0
13T	16T	1131	800	280	400	74.20	424.12	0
13T	11T	2151	0	0	400	119.84	424.12	0
13T	00							
15	0	0	0					
14T	15T	1131	25	15	400	186.71	518.19	0
14T	00							
15	5	10	0					
15T	00							
15	6	0	0					
16T	17T	1131	300	180	400	79.82	482.12	0
16T	12T	2151	0	0	400	220.77	482.12	0
16T	00							
100	50	50	300					
17T	18T	1131	250	140	400	128.37	518.19	0
17T	00							
25	0	15	0					
18T	19T	1131	225	115	400	91.03	586.05	0
18T	00							
25	0	0	0					

Table 4.3 Network Data - Input to the Input Conversion System (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
19T	20T	1131	200	100	400	104.13	652.03	0
19T	00							
15	0	0	0					
20T	00							
100	0	0	120					
21T	22T	1131	600	104	400	208.33	404.59	0
21T	00							
37	0	0	0					
22T	23T	1131	50	33	400	100.57	601.43	0
22T	25T	1131	300	30	400	143.61	601.43	0
22T	00							
41	0	0	0					
23T	24T	1131	25	10	400	94.58	626.64	0
23T	00							
23	0	0	0					
24T	23T	2151	0	0	400	103.52	669.67	0
24T	00							
10	0	0	0					
25T	26T	1131	200	15	400	449.12	711.58	0
25T	00							
15	0	0	0					
26T	00							
15	0	0	160					
27T	28T	1131	600	96	100	206.33	708.39	0
27T	61T	2151	0	0	100	111.17	708.39	0
27T	58T	2151	0	0	100	117.58	708.39	0
27T	31T	2151	0	0	100	194.04	708.39	0
27T	00							
15	10	0	0					
28T	29T	1131	200	26	100	82.49	854.07	0
28T	32T	1131	400	50	100	165.05	854.07	0
28T	56T	2151	0	0	100	94.93	854.07	0
28T	00							
20	10	10	0					
29T	30T	1131	150	16	100	83.73	818.66	0
29T	00							
10	5	2	0					
30T	31T	1131	25	10	100	62.75	784.90	0
30T	55T	2151	0	0	100	181.69	784.90	0
30T	00							
6	3	6	85					
30T	55T	2151	0	0	100	170.45	784.90	0
31T	00							
10	5	5	3					
32T	57T	2151	0	0	100	184.64	997.87	0
32T	00							
50	10	10	130					
33T	34T	1121	600	50	100	232.74	213.21	4
33T	35T	1121	600	96	100	265.34	213.21	3
33T	00							
100	50	50	0					

Table 4.3 Network Data - Input to the Input Conversion System (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
34T	53T	2171	0	0	100	197.35	386.67	0
34T	00							
50 50	0 0							
35T	36T	1121	200	25	100	102.53	449.57	3
35T	52T	2171	0	0	100	190.29	449.57	0
35T	00							
71 0	0 0							
36T	52T	2171	0	0	100	172.92	484.92	0
36T	00							
25 0	0 0							
37T	38T	1131	600	68	200	138.41	419.12	0
37T	00							
42 0	0 0							
38T	39T	1131	400	46	200	149.00	468.62	0
38T	00							
22 5	0 0							
39T	40T	1131	300	31	200	92.44	559.01	0
39T	51T	2151	0	0	200	247.04	559.01	0
39T	00							
15 6	0 0							
40T	41T	1131	200	25	200	91.14	620.22	0
40T	50T	2151	0	0	200	150.25	620.22	0
40T	00							
6 3	3 3							
41T	00							
25 5	5 265							
42T	43T	1131	100	31	100	81.25	331.16	0
42T	46T	1131	75	45	100	84.42	331.16	0
42T	00							
22 0	0 0							
43T	44T	1131	75	21	100	81.62	390.32	0
43T	00							
10 5	0 0							
44T	45T	1131	50	15	100	87.05	422.35	0
44T	46T	2151	0	0	100	77.23	422.35	0
44T	00							
6 0	0 0							
45T	48T	2151	0	0	100	127.92	493.24	0
45T	49T	2151	0	0	100	139.21	493.24	0
45T	00							
15 5	5 375							
46T	44T	2151	0	0	100	78.20	367.49	0
46T	47T	1131	50	25	100	130.48	367.49	0
46T	48T	1131	11	5	100	96.56	367.49	0
46T	00							
15 0	0 0							
47T	00							
25 10	5 0							
48T	45T	2151	0	0	100	133.64	425.02	0
48T	49T	2151	0	0	100	114.24	425.02	0

Table 4.3. Network Data - Input to the Input Conversion System (con'd)

FROM NODE	TO NODE	ARC CODE	TOTAL LINES	USED LINES	GEOG. CODE	ARC LENGTH (METRES)	AIRLINE DISTANCE (METRES)	EXCESS FACILITY
48T	00							
5	5	0	0					
49T	00							
15	6	5	5					
50T	51T	2151	0	0	200	97.12	703.95	0
50T	00							
6	0	0	6					
51T	50T	2151	0	0	200	124.24	718.88	0
51T	00							
10	10	5	35					
52T	00							
0	0	50	10					
53T	00							
17	10	10	20					
54T	53T	2151	0	0	100	264.27	610.77	0
54T	00							
40	10	10	10					
55T	54T	2151	0	0	100	187.67	727.04	0
55T	00							
10	10	10	0					
56T	57T	2151	0	0	100	129.05	890.92	0
56T	58T	2151	0	0	100	84.69	890.92	0
56T	00							
6	5	0	0					
57T	00							
10	5	4	0					
58T	56T	2151	0	0	100	94.78	821.57	0
58T	59T	2151	0	0	100	155.64	821.57	0
58T	00							
10	10	5	0					
59T	57T	2151	0	0	100	104.47	964.02	0
59T	60T	2151	0	0	100	130.43	964.02	0
59T	00							
5	7	11	3					
60T	00							
0	2	3	10					
61T	58T	2151	0	0	100	173.34	710.48	0
61T	62T	2151	0	0	100	88.26	710.48	0
61T	00							
15	15	10	6					
62T	59T	2151	0	0	100	248.82	767.84	0
62T	60T	2151	0	0	100	224.71	767.84	0
62T	00							
0	300	0	100					
63T	61T	2151	0	0	100	113.29	635.44	0
63T	62T	2151	0	0	100	165.77	635.44	0
63T	24T	2151	0	0	100	122.40	635.44	0
63T	00							
5	5	5	4					

4.1.1 Data Format for the Input Conversion System

The format in which information has to be fed into the computer is very critical for the working of the model. This section outlines the data decks and the sequence in which they are to be supplied to the programs.

Data set #1 contains information required by the input conversion system. It consists of four control cards followed by the network data illustrated in Table 4.3. The first card in the deck contains the problem title not exceeding 80 characters in length. The title used in the test was "SUBSCRIBER LOOP OPTIMIZATION".

The second data card in the deck contains a string of 36 characters. These characters are used by the input conversion system in designating a code name to the nodes in the network. Such a system enables more nodes to be accommodated with minimum space requirements. To illustrate, consider a situation where only three characters can be used to designate a node. With a numerical code, each node can take on a value between 0 and 999. Therefore, the maximum number of nodes in this case is 1000. With a code using the 26 letters of the English alphabet in addition to the ten digits, as many as 46,656 nodes can be handled in the same situation. The characters used on the second card can be any

one among those available on a keypunch/terminal. The only condition that has to be satisfied is that one character may occur only once in the string specified. The string:

0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZ

was used in the test problem.

The third card contains the number of periods in the planning horizon considered. Four periods were considered while testing the programs. The first three periods represented the first, second and the third year respectively and the fourth period covered years four through to the time required by the switching center to reach ultimate capacity. It was assumed that it would take 30 years for the switching center to attain its ultimate capacity.

On the fourth card in data set #1, the number of technologies that are explicitly considered in each period are specified. In testing the model, it was not possible to collect specific cost data for the different technologies available in the telecommunications industry. Therefore, only one technology was considered each period, and the general technological trend curve was used to forecast future costs.

The network information shown in Table 4.3 follows the four control cards. The following codes that are used in the input conversion system have direct interaction with the cost model , and are used by the cost model in computing the

arc cost.

<u>Codes of the Variables Used in the Input Conversion System</u>

ARCODE(I) A variable used to define the type of existing plant or the type of plant that can be installed in the arc, I. It is a four digit numerical code with digits, IE, IT, IC, and IS, where,

IE=1 for existing plant, and,
 =2 for new plant,

IT represents the type of technology used/permitted,

IC=1 refers to U/G cable,
 =2 refers to aerial cable, and
 =3 refers to buried cable,
 =4 indicates that types 1&2 are permitted,
 =5 indicates that types 1&3 are permitted,
 =6 indicates that types 2&3 are permitted, and,
 =7 means that there are no constraints on the type of plant to be used, and,

IS=1 refers to paired cable,
 =2 refers to coaxial cable, and
 =3 indicates that either is allowed.

DIST(I) A variable that denotes the length of cable required for the arc,I.

GAUGE(I) Stands for the airline distance of the beginning node of the arc,I, from the switching center.

GEOG(I) A three digit integer describing the geographic

condition of the arc,I. The digits have a value between zero and five. "1" denotes soft soil, "2" a hard area, "3" ravine and uneven surface , "4" a paved area and "5" a swamp. If three conditions occur simultaneously the code has no zeros. If less than three conditions are prevalent, the code has dummy zero(s) as its last digit(s).

ICAP1 An integer referring to the lowest capacity an arc is designed for.

ICAP2 An integer referring to the upper limit on the capacity of an arc.

ITYPE Denotes the type of plant used in the arc. The number codes used for describing an arc are:

1=underground paired cable,

2=aerial paired cable,

3=buried paired cable,

4=underground coaxial cable,

5=aerial coaxial cable, and

6=buried coaxial cable.

KODE A three digit code used to describe an arc. The different types of arcs and the corresponding digits of CODE are:

SINK-SOURCE	0,0,0
SOURCE-XM I (SWITCHING CENTER)	1,0,0
SOURCE-XM I (OTHER NODES)	0,0,0
XM I-XMIJ (EXISTING PLANT)	2,1,ITYPE

	XM I-XMIJ (PRIMARY)	2,2,ITYPE
	XM I-XMIJ (NON-PRIMARY)	2,3,ITYPE
	(If XM I represents a switching center "6" is used in place of "2" as the first digit)	
	XM I-SINK	0,0,0
	XM I-X I (DEMAND POINT)	0,0,0
	XMIJ-XM J	3,0,0
	XMIJ-YMIJ	4,0,0
	XMIJ-SINK	4,0,0
	X I-SINK	5,0,0
LINES(I)	A variable representing the number of 100 pair cables that can be installed in the arc,I with the existing facilities such as poles or conduits.	

Demand points are identified by placing zeros in place of ending node codes. The card following a demand point so designated, must contain the periodic line requirements; total requirements for the first period and the increments for the following periods.

4.1.2 The Master Control Unit and The Output Conversion System

In the master control unit, there are four computer programs namely capacitate [27], update1 [27],

update2 [27] and the master program PNET. The operation of the program is summarized in the flow chart shown in Figure 4.2.

Table 4.4 gives the structure of the input to the master program . The optimization program, PNET outputs the final network by specifying for each arc the plant (flow) that will be added, in a format similar to that shown in Table 4.5.

The output information consists of;

1. the beginning and ending nodes,
2. the unit cost per flow (the unit cost of plant),
3. the lower and upper bounds that were specified,
4. the actual flow, Xij, which is the same as the capacity of the plant installed,
5. the total cost of plant, and
6. the marginal cost, which is the change in total cost affected by increasing the capacity of the arc by one additional line.

In addition PNET also reports the total cost, the number of iterations carried out and whether or not an optimal solution has been found.

The output conversion system outputs the following information;

1. the construction information which includes ,(note Table 4.6);

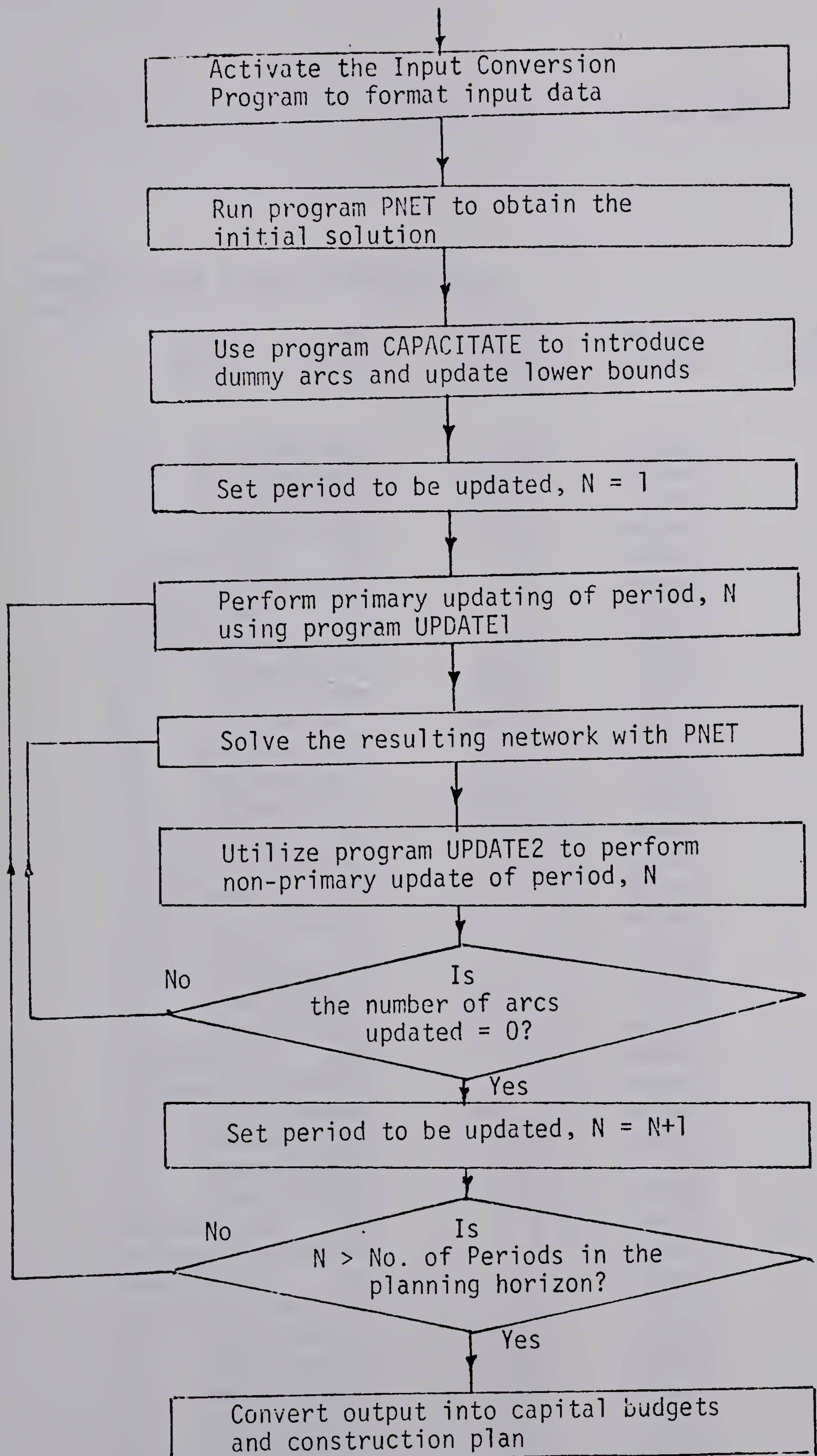


Figure 4.2 Flow Diagram of the Total Optimization Process

Table 4.4 Structure of the Input to the PNET program

```
BEGIN
SUBSCRIBER LOOP OPTIMIZATION
ARCS
         FROM       TO        UNIT       UPPER      LOWER
         NODE     NODE        COST       BOUND      BOUND


    00     00100001002         564        9400          0
    00     00100001002        3887       99999          0
    00     00100001003        1551        3600          0
    00     00100001003        4055       99999          0
    0000100200     002           0       99999          0
    0000100210001002             0       99999          0
    0000100300     003           0       99999          0
    0000100310001003             0       99999          0
    00     00200002005        2551        7200          0
    00     00200002005        4698       99999          0
    00     0020000200X        4934        1200          0
    00     0020000200X        4214       99999          0
    00     00200002011       17073        1000          0
    00     00200002011       29791       99999          0
    0000200500     005           0       99999          0
    0000200510002005             0       99999          0
    0000200X00     00X           0       99999          0
    0000200X1000200X             0       99999          0
    0000201100     011           0       99999          0
    0000201110002011             0       99999          0
    00     00300003004        2994        3600          0
    00     00300003004        4486       99999          0
    0000300400     004           0       99999          0
    0000300410003004             0       99999          0
    00     0040000400C       14171       99999          0
    00     0040000400C         317       99999          0
    00     00400004016         303        1800          0
    00     00400004016         927       99999          0
    0000400C00     00C           0       99999          0
    0000400C1000400C             0       99999          0
    0000401600     016           0       99999          0
    0000401610004016             0       99999          0
    00     00500005006        7489        2400          0
    00     00500005006        5254       99999          0
    00     00500005007        4272        2400          0
    00     00500005007        4531       99999          0
    00     00500005008         226        2400          0
    00     00500005008         888       99999          0
    0000500600     006           0       99999          0
 END
```

Table 4.5 Sample Output of the Master Optimization Program, PNET

```
*****   LUSOL    0

*****   SKIP     0

*****   REPORT   2

*****   SOLVE    1
PROBLEM TITLE      SUBSCRIBER LOOP OPTIMIZATION

OPTIMAL SOLUTION

SOURCES=   830    SINKS=     0    TOTAL NODES=   830    ARCS=   2394

OBJ FCN=          530195968.    NO. ITER=   328
```

ARC NUMBER	FROM NODE	TO NODE	UNIT COST	UPPER BOUND	LOWER BOUND	FLOW	ARC COST	MARG COST
1	00 001	00001002	564	9400	9400	9400	5301600	20564
2	00 001	00001002	3887	99999	0	0	0	23887
3	00 001	00001003	1551	3600	3600	3600	5583600	21551
4	00 001	00001003	4055	99999	0	0	0	24055
5	00001002	00 002	0	99999	2161	9090	0	0
6	00001002	10001002	0	99999	0	310	0	0
7	00001003	00 003	0	99999	159	3220	0	0
8	00001003	10001003	0	99999	0	380	0	0
9	00 002	SINK	0	99999	0	590	0	0
10	00 002	00002005	2551	7200	7200	7200	18367200	2551
11	00 002	00002005	4698	99999	0	0	0	4698
12	00 002	0000200X	4934	1200	0	0	0	4934
13	00 002	0000200X	4232	300	300	300	1269600	4232
14	00 002	0000200X	14323	99999	0	0	0	14323
15	00 002	00002011	17073	1000	1000	1000	17073000	17073
16	00 002	00002011	29791	99999	0	0	0	29791
17	00002005	00 005	0	99999	1227	5766	0	0
18	00002005	10002005	0	99999	0	1434	0	0
19	0000200X	00 00X	0	99999	263	280	0	0
20	0000200X	1000200X	0	99999	0	20	0	0
21	00002011	00 011	0	99999	163	686	0	0
22	00002011	10002011	0	99999	0	314	0	0
23	00 003	SINK	0	99999	0	0	0	0
24	00 003	00003004	2994	3600	3600	3600	10778400	2994
25	00 003	00003004	4486	99999	0	0	0	4486
26	00003004	00 004	0	99999	159	3220	0	0
27	00003004	10003004	0	99999	0	380	0	0
28	00 004	SINK	0	99999	0	1420	0	0

Table 4.6 Construction Plan for Switching Center XYZ

SWITCHING CENTER: XYZ DATE: 78:08:01

CONSTRUCTION PLAN SUMMARY
(SUBSCRIBER LOOP PLANT)

FROM NODE	TO NODE	CAPACITY ADDITIONS	INSTALLED CAPACITY	UTILIZED CAPACITY	PLANT CLASS	CABLE TYPE
1	2	0	9400	3526	1	
1	3	0	3600	564	1	
2	5	0	7200	2636	1	
2	33	0	1200	413	1	
2	37	0	1000	477	1	
3	4	0	3600	564	1	
4	12	25	25	25	3	26-ALPETH
4	42	0	1800	197	3	
5	6	0	2400	7	1	
5	7	0	2400	1004	1	
5	8	0	2400	1570	3	
6	54	11	11	7	3	26-ALPETH
7	27	0	600	496	3	
7	63	600	600	435	3	26-ALPETH
8	21	0	1200	301	3	
8	9	0	1200	233	3	
9	10	0	200	33	3	
9	13	0	600	599	3	
10	11	0	100	6	3	
13	14	0	50	36	3	
13	16	0	800	400	3	
14	15	0	25	15	3	
16	17	0	300	275	3	
17	18	0	250	250	3	
18	19	0	225	215	3	
19	20	0	200	100	3	
21	22	0	600	264	3	
22	23	0	50	33	3	
22	25	0	300	190	3	
23	24	0	25	10	3	
25	26	0	200	15	3	
27	28	0	600	420	3	

Table 4.6 Construction Plan for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

CONSTRUCTION PLAN SUMMARY
(SUBSCRIBER LOOP PLANT)

FROM NODE	TO NODE	CAPACITY ADDITIONS	INSTALLED CAPACITY	UTILIZED CAPACITY	PLANT CLASS	CABLE TYPE
27	58	37	37	31	3	26-ALPETH
27	31	11	11	10	3	26-ALPETH
28	29	0	200	160	3	
28	32	0	400	50	3	
29	30	0	150	89	3	
30	55	100	100	0	3	26-ALPETH
33	34	0	600	107	2	
33	35	0	600	96	2	
34	53	75	75	17	3	26-ALPETH
35	36	0	200	25	2	
37	38	0	600	422	3	
38	39	0	400	331	3	
39	40	0	300	206	3	
39	51	16	16	16	3	26-ALPETH
40	41	0	200	25	3	
42	43	0	100	85	3	
42	46	0	75	66	3	
43	44	0	75	56	3	
44	45	0	50	30	3	
45	49	16	16	15	3	26-ALPETH
46	47	0	50	25	3	
46	48	0	11	6	3	
48	49	11	11	0	3	26-ALPETH
51	50	11	11	6	3	26-ALPETH
55	54	75	75	33	3	26-ALPETH
56	57	11	11	10	3	26-ALPETH
58	56	16	16	16	3	26-ALPETH
58	59	11	11	5	3	26-ALPETH
62	60	16	16	0	3	26-ALPETH
63	61	16	16	15	3	26-ALPETH
63	62	600	600	15	3	26-ALPETH

a) the different arcs in the network,

b) the capacity additions to be made to those arcs in the first period,

c) the type of plant and cable used, and

d) the total installed and utilized capacities for the arcs at the end of the period.

2. the capital budgeting information ,such as (note Table 4.7):

a) the quantity of plant required by type and sizes

b) the calculated unit construction cost for each type of plant, and

c) the total estimated cost for the different type of plant .

Table 4.8 shows the capital budget summary for outside plant facilities, and Table 4.9 gives the switching center capacity requirements.

4.2 The Cost Model

The cost model as an integral unit of the above systems performs the cost computations as and when it is required to do so. The primary classification of plant is identified by the code ITYPE. It identifies the following major types of plant;

Table 4.7 Capital Budget by Periods for Switching Center XYZ

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 1 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	908.	1.52	1377.23
CABLE	18-26ALPETH	1	819.	1.54	1258.72
CABLE	37-26ALPETH	1	174.	1.74	302.42
CABLE	50-26ALPETH	1	118.	2.55	299.44
CABLE	100-26ALPETH	1	385.	2.71	1042.81
CABLE	150-26ALPETH	1	170.	2.12	361.23
CABLE	900-26ALPETH	1	325.	15.75	5117.28

Table 4.7 Capital Budget by Periods for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:03:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 2 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	943.	1.47	1384.94
CABLE	18-26ALPETH	1	95.	2.40	227.04
CABLE	50-26ALPETH	1	113.	2.61	295.83
CABLE	75-26ALPETH	1	118.	2.98	349.93
CABLE	100-26ALPETH	1	190.	2.72	517.65

Table 4.7 Capital Budget by Periods for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 3 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION	UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	721.	1.33	960.86

Table 4.7 Capital Budget by Periods for Switching Center XYZ (con'd)

SWITCHING CENTER: XYZ DATE: 78:08:01

***** SUBSCRIBER LOOP CAPITAL INVESTMENT BUDGET FOR PERIOD 4 *****

1CLASS OF PLANT: U/G PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

2CLASS OF PLANT: AERIAL PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST

3CLASS OF PLANT: BURIED PAIRED CABLE

ACCOUNT DESCRIPTION		UNIT	TOTAL UNITS	UNIT CONSTR. COST	TOTAL ESTIMATED COST
CABLE	12-26ALPETH	1	862.	1.85	1598.51
CABLE	18-26ALPETH	1	92.	2.56	236.47
CABLE	37-26ALPETH	1	104.	2.63	274.26
CABLE	50-26ALPETH	1	331.	2.08	689.40
CABLE	150-26ALPETH	1	91.	4.62	421.23
CABLE	400-26ALPETH	1	178.	7.96	1416.58
CABLE	600-26ALPETH	1	250.	12.18	3040.17

Table 4.8 Capital Budget Summary for Switching Center XYZ

SWITCHING CENTER: XYZ DATE: 78:08:01

SUBSCRIBER LOOP CAPITAL INVESTMENT SUMMARY

CLASS OF PLANT	1	2	3	4
U/G CABLE	0.0	0.0	0.0	0.0
AERIAL CABLE	0.0	0.0	0.0	0.0
BURIED CABLE	9759.12	2775.39	960.86	7676.61
U/G COAX CABLE	0.0	0.0	0.0	0.0
AER COAX CABLE	0.0	0.0	0.0	0.0
BUR COAX CABLE	0.0	0.0	0.0	0.0
U/G CONDUIT	0.0	0.0	0.0	0.0
POLES	0.0	0.0	0.0	0.0
LINE CONC.	0.0	0.0	0.0	0.0

Table 4.9 Switching Center Capacities

SWITCHING CENTER: XYZ DATE: 78:08:01

SWITCHING CENTER CAPACITIES
(BY TYPE OF TECHNOLOGY)

	1	2	3
PERIOD 1	13000		
PERIOD 2	0		
PERIOD 3	0		
PERIOD 4	0		

1. underground cable plant ,
2. aerial cable plant,
3. buried cable plant,
4. coaxial underground plant ,
5. coaxial aerial plant , and
6. coaxial buried plant.

The above major groupings is once again divided into the following categories in order to account for the labor cost, material cost and overheads. The order is selected in this convenient form for simplifying the programming:

1. aerial cable ,
2. poles and associated equipment ,
3. aerial coaxial cable ,
4. buried cable ,
5. buried coaxial cable ,
6. underground cable,
7. ducts and vaults ,
8. underground coaxial cable ,and
9. miscelleneous equipment.

Another variable ISPEC will codify, whether the arcs need loading or not, the type of cable to be used (e.g Stalpeth, Alpeth) and the gauge of the cable. The code SPEC remembers the design specification as applicable to the types of plant . (Refer to Appendix A.)

Whenever the cost model is required to do the computations, it obtains from the input conversion system the code referring to the following information in any given arc;

1. geography difficulty factor -IGEO,
2. the distance between the nodes -DIST,
3. the code of the type of plant -ITYPE,
4. lower capacity of flow -CAPI,
5. upper capacity of flow -CAP2,
6. the period under consideration -NYEAR,
7. distance of the node from switching center -Gauge, and
8. number of conduits available if any . -Lines

Figure 4.3 is a simplified flow diagram of the cost computation procedure.

4.2.1 Preparing the Data bank for the Cost Model

The cost data was divided into two sets of data. The first contains the data needed to calculate the direct labor cost, the material cost, and also includes the design specifications as applied to the plant, The second set contains all the financial data, plus the technology parameters, and the operating cost information.By specifying the statements ' 5=THEDATA, 6=21', the cost data given in

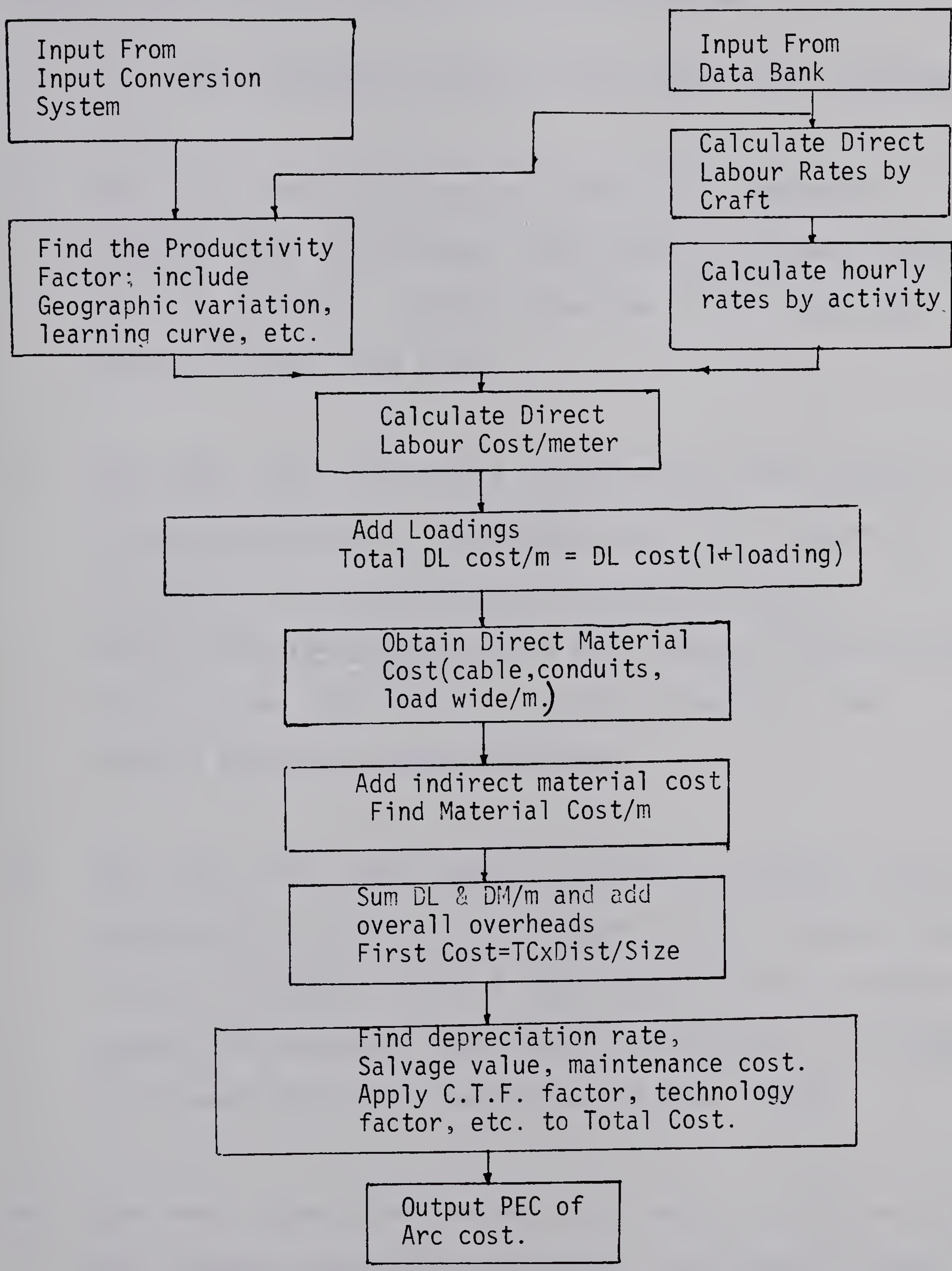


Figure 4.3 Flow Diagram Showing the Calculation of Major Cost Components

table 4.10 will be read by the main program.

The following explains the input data statements :

1. The first five statements contain the number of periods(004) considered, the duration of each period, and the weighted average duration of the remaining period in the life span.

2. The next five statements contains the wage payments for each type of craft considered. The total wages are recorded by the following categories:regular wages,overtime wages,hiring and training costs,employee termination costs,and any shift premium if one exists.These are annual figures.

3. The next five rows contain the total manhours and the productivity factor as estimated by the engineer in charge. Normally craft A type contains the maximum number of personnel and craft E the least. The number of absent days also decreases in that order.

4. The next eight rows contain the matrix of direct time for various functions performed. The direct times are arrived at by studying the various costing manuals and an idea of the work units involved .

5. The next five rows contain the percentage work

contribution by craft type for different functions performed. They are expressed in decimals.

6. The next six rows contain the geography difficulty factors for different types of activities. It was assumed that the area selected for study does not contain any swamp area.

7. The next six rows contain the direct labor loadings and material loadings alternatively against the major groupings of the plant. Table 3.7 shows the format. The loadings are assumed to be equal for different types of plant. A general material price discount of ten percent is assumed.

8. The next line refers to the number of gauges of plant considered. In the sample problem four different gauges were assumed. This value can be varied.

9. The next four line refer to these gauges. The gauges that was selected for testing was 26, 24, 22, 19, gauge cables.

10. The next line refer to the type of cable considered (e.g. Stalpeth, Alpeth etc.)identified by code types.

11. The next four lines denote the limiting distances for

various gauges. The first two figures express the limiting distances for 26 gauge and 24 gauge cable under no loading conditions. The rest are for different gauges under loaded condition.

12. The next line is for the identification of the cable type that suits a particular type of plant. As an example stalpeth for underground cable, Alpeth for aerial or buried cable.

13. The next line specifies the maximum number of different pairs of cable available under the different gauge category. This is followed by the number of pairs of cables and their cost by standard length. The standard length used is one kilo-meter. The third column specifies the terminal equipment necessary at each node. Steps 11,12,13 are repeated for the underground, buried, aerial, underground coaxial, buried coaxial and aerial coaxial types of cables. The coaxial cable, in our example problem is not considered.

14. After the above figures the number of different types of manholes is stated. Seven different type of manholes were considered.

15. Next, the cost of those different types of manholes and their frequency of usage obtained from past data is

stated.

16. The next line states the loading coil and capacitor intervals, expressed in meters.

17. This data is followed by the different type of loading coils, and capacitors available.

18. The next five lines refer to the average cost of loading coils and other accessories. The second column refers to their frequency of usage. This data is repeated for all the different types of plant, since different plant needs different types of loadings coils and sizes of capacitors etc. However, while testing it was assumed that the same set of loading coils can be used with the different types of plant.

19. The next line represents the number of different sizes of conduits available (e.g 1",2",3").

20. The next line refers to the maximum size cable that can be pulled through the smallest conduit available. The second column refers to the different number of number of ways of conduit that can be placed.

21. The next three lines specifies the cost per meter of conduit against the different number of ways

considered. Steps 20 and 21 are repeated for all the available size of conduits in that order.

22. The next line refers to the average cost per pole, the cost of cross arms and other accessaries expressed as a percentage of the average cost of pole. It also includes the average distance between poles.

23. The last line refers to the overall overhead percentages such as vehicle ,tool, contract expenses, engineering, and administration marketing and contingency expences.

The second set of data contains the following ;

1. The first line consists of the tax rate, the debt-equity ratio, the interest rate on equity capital, interest rate on debt capital and the general inflation rate ; expressed in decimal form .

2. The next line refers to the ultimate life span considered (i.e 30 years).

3. The next line refers to the depreciation rates of different types of plant in the following order,
   a) aerial cable,
   b) poles,

c) aerial coaxial cable ,

d) buried cable,

e) buried coaxial cable,

f) underground cable,

g) vaults and ducts,

h) underground coaxial cable, and

i) miscelleneous equipments such as load coils, capacitors etc.

4. The next line refers to the percentage salvage values of the existing plant at the end of their estimated life.

5. The next line refers to the technology parameters, and the rate of increase in operating costs. Refer to Appendix C to obtain the parameters.

6. The next line refers to the average expected life of the existing plant.

7. The next line refers to the percentage salvage value of the plant if it is newly installed. It is repeated for the different types of plant.

8. The next eight lines states the anticipated operating cost for the different types of plant over the next

Table 4.10 Cost Data Used for Testing of the Model

```
                                                                        DATA CARD
                                 DATA/ COMMENTS                           NUMBER
*    THE NUMBER OF PERIODS IN THE PLANNING HORIZON                           1
004
*    THE EQUIVALENT DURATION OF EACH PERIOD                                  2
001                                                                          3
001                                                                          4
001                                                                          5
010
*     THE PAYROLL COSIS BY CRAFT TYPE CLSSIFIED UNDER FIVE CATEGORIZS        6
 1254400. 124800.   124800.   62400.    107200.                              7
 1593440. 168000.   168000.   84000.    146160.                              8
 1347720. 134772.   134632.50 67320.    116160.                              9
 1026900. 102690.   102690.   51345.    88200.                              10
 540000.  54000.    54000.    27000.    46350.
*     TOTAL MANHOURS (YEARLY) AND THE PRODUCTIVITY FACTORS FOR EACH CRAFT   11
 160000.  .72                                                               12
 168000.  .75                                                               13
 132000.  .80                                                               14
 90000.   .70                                                               15
 45000.   .74
*     TIME REQUIRED IN HOURS FOR EACH SUB-ACTIVITY (ONE ROW FOR ONE ACTIVITY) 16
0.3851    0.9810    0.2665    0.6066    0.5449                              17
0.0233    0.0054    0.0066    0.1783    0.0305                              18
0.5000    0.3833    0.2199    0.0       0.1666                              19
0.0107    0.0016    0.0056    0.0451    0.6199                              20
0.0833    0.0250    0.0366    0.0       0.0200                              21
0.1666    0.1115    0.0733    0.0       0.2066                              22
0.0103    0.0016    0.1466    0.0451    0.4084                              23
0.4908    0.2511    0.7666    0.3750    0.0
*     PERCENTAGE OF WORK CONTRIBUTED BY PEOPLE IN ONE CRAFT (ONE ROW FOR EACH ACTIVITY)
                                                  .05       .5        0.    24
 .1        .5        .6        .5        .1       .05       .1        .2    25
 .1        .1        .0        .1        .3       .05       .1        .5    26
 .5        .1        .1        .1        .3       .6        .1        .14   27
 .14       .14       .14       .14       .14      .14       .14       .14   28
 .14       .14       .14       .14       .14      .14       .14       .14
*     GEOGRAPHIC DIFFICULTY FACTORS BY TYPE OF TERRAIN AND ACTIVITY         29
 1.        1.07      1.12      1.05                                         30
 1.        1.05      1.15      1.1                                          31
 1.        1.25      1.18      1.20                                         32
 1.        1.04      1.06      1.1                                          33
 1.        1.07      1.12      1.2                                          34
 1.        1.12      1.14      1.16                                         35
 1.        1.03      1.04      1.04
*     LOADINGS ON MATERIAL AND LABOR, PLACED ALTERNATIVELY (ONE ROW FOR ONE CLASS OF PLANT)
                                                            25.     -10.    36
 45.       2.        25.       2.        7.       0.        25.     -10.    37
 45.       2.        25.       2.        7.       0.        25.     -10.    38
 45.       2.        25.       2.        7.       0.        25.     -10.    39
 45.       2.        25.       2.        7.       0.        25.     -10.    40
 45.       2.        25.       2.        7.       0.        25.     -10.    41
 45.       2.        25.       2.        7.       0.
*     TOTAL NUMBER OF GAUGES AVAILABLE                                      42
004
```

Table 4.10 Cost Data Used for Testing of the Model (con'd)

```
*     THE DIFFERENT GAUGES AVAILABLE
026                                                                          43
024                                                                          44
022                                                                          45
019                                                                          46
*     TOTAL NUMBER OF CABLE SIZES
 35                                                                          47
*     THE DIFFERENT SIZES OF CABLE AVAILABLE (FOUR COLUMNS PER SIZE)
   4   6  11  12  16  18  25  37  50  75 100 150 200 300 400 450 500 550 600 800   48
 9001000110012001400150016001800210024002700280030003300360O                    49
*     CABLE COST DATA
*     UNDERGROUND CABLE
*     NUMBER OF SUBCLASSIFICATIONS
001                                                                          50
*     DESIGN SPECIFICATIONS
*     THE NUMBER OF DIFFERENT DESIGN CATEGORIES
006                                                                          51
*     THE DIFFERENT DISTANCES AND THE CORRESPONDING DESIGN SPECIFICATIONS
4850.     01026                                                              52
5450.     01024                                                              53
7475.     11026                                                              54
11670.    11024                                                              55
22120.    11022                                                              56
22730.    11019                                                              57
*     NUMBER OF GAUGES AVAILABLE IN UNDERGROUND PLANT AND SUBCLASS 1 (STALPETH)
*     FOLLOWED BY THE NUMBER OF SIZES OF PLANT AND THE ASSOCIATED COSTS
*     THE COSTS FOR THE PLANT ARE THE MATERIAL COSTS PER UNIT OF MEASUREMENT
  4                                                                          58
 17                                                                          59
    200.00       3.63      23.28                                             60
    300.00       5.17      21.24                                             61
    400.00       6.45      15.35                                             62
    600.00       9.39      17.46                                             63
    800.00      12.26      18.48                                             64
    900.00      13.67      23.21                                             65
   1200.00      18.20      19.32                                             66
   1500.00      22.60      15.46                                             67
   1800.00      26.91      20.39                                             68
   2100.00      31.39      18.00                                             69
   2400.00      35.79      16.29                                             70
   2700.00      40.23      17.97                                             71
   2800.00      41.34      19.13                                             72
   3000.00      44.59      22.30                                             73
   3300.00      49.04      23.24                                             74
   3600.00      53.39      18.40                                             75
   3900.00      57.91      22.29                                             76
 11                                                                          77
    200.00       4.67      24.67                                             78
    300.00       6.70      24.87                                             79
    400.00       8.57      15.56                                             80
    600.00      12.61      17.31                                             81
    800.00      16.55      24.54                                             82
    900.00      18.55      19.11                                             83
```

Table 4.10 Cost Data Used for Testing of the Model (con'd)

```
  1200.00      24.66      16.46
  1500.00      30.89      21.82
  1800.00      36.98      19.58
  2100.00      42.85      15.93
  2400.00      49.16      22.37
13
   100.00       3.85      19.62
   150.00       5.13      20.18
   200.00       6.63      24.47
   300.00       9.64      23.69
   400.00      12.72      18.88
   450.00      14.31      19.99
   600.00      18.78      15.08
   800.00      24.71      19.60
   900.00      27.65      23.11
  1000.00      30.69      15.53
  1100.00      33.74      20.03
  1200.00      36.75      24.69
  1500.00      45.70      21.17
11
    25.00       2.68      23.30
    50.00       4.46      22.47
    75.00       6.50      23.62
   100.00       8.36      16.99
   150.00      12.26      23.37
   200.00      16.02      19.48
   300.00      23.68      15.56
   400.00      31.25      23.04
   450.00      34.96      18.59
   550.00      42.57      24.61
   600.00      46.38      16.05
*     NUMBER OF SUBCLASSES OF PLANT WITHIN AERIAL PLANT
 2
*     NUMBER OF DESIGN CATEGORIES,  FOLLWED BY THE DESIGN DISTANCES AND THE SPECIFICATIONS
 6
4850.      02026
5450.      02024
7475.      12026
11670.     12024
22120.     12022
22730.     12019
*     NUMBER OF GAUGES IN SUBCLASS 1(STALPETH)

*     THE NUMBER OF GAUGES IN SUBCLASS 2(ALPETH)
 4
*     NUMBER OF CABLE SIZES FOR EACH GAUGE, THE SIZES AND THE ASSOCIATED COSTS
*      THE CABLE COSTS ARE IN DOLLARS PER METRE.
 25
     11.00       0.53      24.66
     12.00       0.55      16.29
     16.00       0.62      15.11
     18.00       0.66      16.11
     25.00       0.83      18.12
```

Table 4.10 Cost Data Used for Testing of the Model (con'd)

	50.00	1.24	23.25	131
	75.00	1.75	24.40	132
	100.00	2.23	24.22	133
	150.00	3.11	17.17	134
	200.00	4.22	19.46	135
	300.00	6.10	21.32	136
	400.00	7.88	15.68	137
	500.00	9.81	21.58	138
	600.00	11.44	16.34	139
	800.00	15.13	16.60	140
	900.00	17.02	21.67	141
	1000.00	18.82	19.18	142
	1100.00	20.82	18.87	143
	1200.00	21.89	24.63	144
	1400.00	25.92	15.75	145
	1500.00	27.42	16.48	146
	1800.00	32.21	17.12	147
	2100.00	37.89	22.00	148
	2400.00	43.48	24.68	149
	3000.00	55.36	18.80	150
24				151
	6.00	0.43	20.19	152
	11.00	0.58	21.18	153
	12.00	0.59	17.19	154
	16.00	0.70	21.17	155
	18.00	0.76	16.86	156
	25.00	0.91	20.68	157
	37.00	1.18	24.21	158
	50.00	1.51	18.97	159
	75.00	2.13	22.79	160
	100.00	2.86	22.25	161
	150.00	4.25	19.85	162
	200.00	5.53	15.27	163
	300.00	8.05	19.13	164
	400.00	10.51	20.11	165
	500.00	13.05	17.51	166
	600.00	15.46	19.33	167
	800.00	20.32	22.28	168
	900.00	22.80	22.62	169
	1000.00	25.63	17.99	170
	1200.00	30.65	23.77	171
	1500.00	36.75	20.08	172
	1800.00	44.61	15.96	173
	2100.00	49.35	19.03	174
	2400.00	55.34	21.82	175
18				176
	6.00	0.49	18.79	177
	11.00	0.68	23.53	178
	12.00	0.71	21.80	179
	16.00	0.82	23.99	180
	18.00	0.90	19.17	181
	25.00	1.16	18.13	182
	37.00	1.52	19.90	183

Table 4.10 Cost Data Used for Testing of the Model (con'd)

```
     50.00         1.96       15.55
     75.00         3.16       16.95
    100.00         4.05       15.30
    150.00         5.68       23.52
    200.00         7.46       18.78
    300.00        10.87       18.41
    400.00        14.37       20.31
    500.00        17.56       23.89
    600.00        21.17       18.86
    900.00        32.28       16.36
   1200.00        42.77       20.20
 14
      6.00         0.67       21.24
     11.00         1.03       21.21
     12.00         1.10       16.68
     16.00         1.34       20.05
     18.00         1.48       18.73
     25.00         1.88       15.13
     37.00         2.94       16.08
     50.00         3.79       24.63
     75.00         5.34       24.38
    100.00         6.92       18.18
    150.00        10.13       24.12
    200.00        13.26       18.34
    300.00        19.42       19.64
    400.00        25.81       15.72
*     NUMBER OF SUBCLASSES OF PLANT IN BURIED CABLE
  2
*     DESIGN SPECIFICATIONS
  6
4850.       02026
5450.       02024
7475.       12026
11670.      12024
22120.      12022
22730.      12019
*     NUMBER OF GAUGES IN SUBCLASS 1 (STALPETH)

*     NUMBER OF GAUGES IN SUBCLASS 2 (ALPETH)
  4
*     NUMBER OF CABLE SIZES, THE ACTUAL SIZES AND THE ASSOCIATED COSTS FOR EACH GAUGE
*     THE COSTS ARE IN DOLLARS PER METRE
  18
     11.00         0.17       19.00
     12.00         0.17       17.07
     16.00         0.20       15.91
     18.00         0.23       21.25
     25.00         0.26       21.53
     37.00         0.35       17.16
     50.00         0.41       23.01
     75.00         0.60       21.84
    100.00         0.77       15.40
    150.00         1.07       18.62
```

Table 4.10 Cost Data Used for Testing of the Model (con'd)

200.00	1.39	15.13	231
300.00	2.02	17.18	232
400.00	2.63	22.04	233
600.00	3.89	23.86	234
900.00	5.84	18.94	235
1200.00	7.75	23.42	236
1500.00	9.23	17.59	237
1600.00	9.82	19.51	238
16			239
6.00	0.15	19.88	240
11.00	0.20	15.49	241
12.00	0.21	19.28	242
16.00	0.25	21.85	243
18.00	0.26	16.61	244
25.00	0.32	18.19	245
37.00	0.42	20.57	246
50.00	0.54	22.65	247
75.00	0.79	17.78	248
100.00	1.00	16.40	249
150.00	1.45	15.19	250
200.00	1.89	15.29	251
300.00	2.83	23.34	252
400.00	3.78	22.12	253
600.00	5.63	18.89	254
900.00	8.44	19.49	255
16			256
4.00	0.14	18.53	257
6.00	0.16	24.62	258
11.00	0.23	17.59	259
12.00	0.24	17.25	260
16.00	0.29	17.88	261
18.00	0.31	15.53	262
25.00	0.40	18.76	263
37.00	0.55	16.82	264
50.00	0.75	19.50	265
75.00	1.05	16.80	266
100.00	1.36	20.52	267
150.00	2.00	18.65	268
200.00	2.61	16.70	269
300.00	3.77	19.73	270
400.00	4.93	15.86	271
600.00	7.68	15.03	272
14			273
4.00	0.20	17.95	274
6.00	0.25	19.50	275
11.00	0.37	15.62	276
12.00	0.39	24.58	277
16.00	0.48	19.16	278
18.00	0.51	23.53	279
25.00	0.71	16.70	280
37.00	1.04	15.63	281
50.00	1.38	22.95	282
75.00	1.96	21.15	283
100.00	2.57	22.05	284

Table 4.10 Cost Data Used for Testing of the Model (con'd)

```
   150.00       3.78      22.55
   200.00       4.91      23.60
   300.00       7.22      20.05
*     NUMBER OF SUBCLASSES WITHIN UNDERGROUND COAXIAL PLANT
000
*     NUMBER OF SUBCLASSES WITHIN AERIAL COAXIAL PLANT
000
*     NUMBER OF SUBCLASSES WITHIN BURIED COAXIAL PLANT
000
*     THE NUMBER OF DIFFERENT MANHOLES AVAILABLE
007
*     THE MANHOLE COST AND THE NUMBER OF MANHOLES WITH THAT COST
*     THE COSTS ARE IN DOLLARS PER MANHOLE
3300.             1
3450.             1
3250.             1
3900.             1
3800.             1
5500.             1
1250.             1
*     LOADING INTERVAL IN METERS
  1820
*     THE NUMBER OF DIFFERENT TYPE OF LOADING EQUIPMENT AVAILABLE IN EACH CLASS OF PLANT
*     FOLLOWED BY THE COSTS AND THE NUMBER OF COILS IN THAT CATEGORY
*     THE COSTS ARE IN DOLLARS PER LOADING SET.
  5
563.              1
1045.             1
1497.             1
1932.             1
4668.             1
  5
563.              1
1045.             1
1497.             1
1932.             1
4668.             1
  5
563.              1
1045.             1
1497.             1
1932.             1
4668.             1
  5
563.              1
1045.             1
1497.             1
1932.             1
4668.             1
  5
563.              1
1045.             1
1497.             1
1932.             1
```

Table 4.10 Cost Data Used for Testing of the Model (con'd)

```
4668.          1                                                        329
  5                                                                     330
563.           1                                                        331
1045.          1                                                        332
1497.          1                                                        333
1932.          1                                                        334
4668.          1                                                        335
*     THE NUMBER OF DIFFERENT SIZES OF CONDUIT AVAILABLE
*     FOLLOWED BY THE MAXIMUM SIZE OF CABLE THE SIZE CAN ACCOMADATE
*     AND THE NUMBER OF DIFFERENT OF WAYS OF CONDUIT IN EACH SIZE
    3                                                                   336
  400     3                                                             337
*     CONDUIT MATERIAL COSTS FOR THE DIFFERENT NUMBER OF WAYS
*     THE CONDUIT COSTS ARE IN DOLLARS PER METRE
  11.3283                                                               338
  22.6566                                                               339
  33.9849                                                               340
  1000     3                                                            341
  11.6726                                                               342
  23.3452                                                               343
  35.0178                                                               344
  3600     3                                                            345
  11.6910                                                               346
  23.3820                                                               347
  35.0730                                                               348
*     POLE COST, POLE EQUIPMENT COST AND THE INTERVAL BETWEEN POLES IN METERS
 150.     20.      30.                                                  349
*     THE OVERHEAD LOADING PERCENTAGES
 17.      20.      5.       25.                                         350
*     THE TAX RATE, DEBT RATIO, INTEREST ON EQUITY, INTEREST ON DEBT AND THE RATE OF INFLATION
.08       .85      .15      .087      .07                               351
*     THE EXPECTED LIFE OF PLANT
 30                                                                     352
*     THE PERCENTAGE DEPRECIATION RATES FOR EACH CATEGORY OF PLANT
9.14 4.24 9.14 6.73 6.73 4.22 2.13 4.22 9.14                            353
*     THE SALVAGE FOR THE NINE CATEGORIES OF PLANT
 0.       0.0      0.       0.        0.                                354
 0.       0.       0.       0.                                          355
*     TECHNOLOGY PARAMETERS AND THE ANNUAL FRACTIONAL INCREASE IN MAINTENENCE
 1.       25.75889  .2460576  .08                                       356
*     THE EXPECTED LIFE OF EXISTING PLANT BY CLASS OF PLANT
       20        20        20        20        20        20             357
*     ESTIMATED SALVAGE FOR EXISTING PLANT AT THE END OF THE USEFUL LIFE BY CATEGORY
 0.       0.       0.       0.        0.                                360
 0.       0.       0.       0.                                          361
*     THE FIRST YEAR'S MAINTENENCE COST BY CATEGORY AND VINTAGE
.001      1.50     .00076   .00003    .00005                            362
.00045    .300     .00067   32.32                                       363
.0009     1.45     .00072   .000025   .000045                           364
.00040    .250     .00062   31.32                                       365
.0008     1.4      .00067   .00002    .00004                            366
.00035    .200     .00057   30.32                                       367
.0007     1.35     .00062   .000015   .000035                           368
.0003     .150     .00052   29.32                                       369
.0006     1.3      .00057   .00001    .00003                            370
.00025    .100     .00047   28.32                                       371
```

four periods.

The computer listing of the data used is found in Table 4.10.

4.3 Test Results and Inference

The goal of the cost model as an integral unit of the optimization model is to obtain a capital budget covering the planning horizon and a construction program for the first period. Hence the construction plan and the capital budget constitute the major portion of output. However, other useful information can also be obtained after each stage in the operation of the total optimization. Since the optimization is carried out in a sequential manner, with the output of one stage forming the input of succeeding stages, the user has the flexibility to examine the results of one iteration and make changes if required. To facilitate this, the program outputs a brief description of the arc, the arc distance, construction costs and the type of plant used after every iteration. At the final stage of the operation, it outputs the details of the periodic budgets giving the total volume, unit construction cost and the estimated cost for each type of plant involved.

4.3.1 Conclusions

The cost model was thorougly tested using hand calculated test cases before the actual use in the total optimization model. Several test runs were made to assess the performance of the model under varying environments. The test conducted on the cost model and the optimization model revealed that the model can be applied to planning of plant investment in subscriber loop facilities. In designing the test problem, attempts were made to simulate situations parallel to those encountered in the real world.

Computer times required for compiling and execution of the programs on an Amdahl 470V/6 computer are tabulated in Table 4.11. The number of nodes in the test network was 830, while the number of arcs varied from around 1900 for the initial run to about 2400 for the final iteration. The computer time required for optimization increases significantly with the number of nodes involved. Therefore, every effort must be made to eliminate nodes that are not critical. Considerable judgement must be exercised at the time the data are prepared in reducing the number of nodes to a minimum. For example, in areas where only one possible route exists, the series of arcs that forms the route can be replaced by a single arc with a cost equivalent to that of the entire route. The cost of running the test

Table 4.11 Computer Time Statistics for the Test Run

Number of Nodes in the Network = 830
Average Number of Arcs = 2132
Number of Periods = 4

Program	Compilation Time (sec.)	Average Execution Time (sec.)	Number of Runs
Cost Model	3.215	.....	9
Input Conversion	1.107	4.441	1
PNET	3.679	10.987	5
CAPACITATE	0.437	7.919	1
UPDATE1	0.463	8.335	4
UPDATE2	0.498	8.500	4
Output Conversion	1.665	5.349	1

problem was around \$100. The cost to test a switching center area would vary depending on the number of actual nodes in the physical network. This cost should not exceed \$1000, but it will vary depending on the ingenuity of the analyst.

The test also revealed that it is desirable to consider five years in the short range if more accurate forecasts can be developed in the future. Since optimization of outside plant is done every year, detailed yearly plans for the time beyond the short range are not useful. So one period, representing the time between the end of the short range forecast and the time when a switching center attains full capacity is sufficient for optimization purposes.

5. SUMMARY AND CONCLUSIONS

The cost model developed as an integral unit of the optimization system, is an attempt at improving the overall effectiveness of planning the outside plant investment in telecommunications carrier industry. The overall aim is to find a near optimal strategy for a construction plan and to output this construction plan and a capital budget by switching center area. The construction plan should be of valuable assistance in manpower planning, job scheduling and control, whereas the capital budget will help in effective financial planning.

The cost model developed, centers around the PNET network optimization program. Several modifications were made to the basic program in order to model the outside plant facilities. The cost model was designed as an interactive program with other programs of the total optimization system. It computes the arc cost per unit of flow for the different types of plant considered in a given arc. The cost model evaluates alternative investment decisions on the basis of net present value analysis . The versatility of the model is increased by incorporating such factors as changing technology ,inflation, varying geographic conditions etc. It is a time sharing type of computer-based system. The model consists of eight different

subroutines, apart from the main program.

A switching center area was chosen as the integral unit that can be used as a building block for planning purposes. Thus, the model developed can be directly applied to the optimization and planning of subscriber loop facilities in a telecommunication industry.

The tests conducted on the model revealed that the model can be adopted in a practical situation, using a planning range consisting of four periods; the first three representing the immediate three years and the last period representing the time duration covering years four through to thirty, which is the estimated time taken by a switching center to reach ultimate capacity. A three year short range planning horizon is recommended because the forecasts beyond three years tend to become inaccurate. A three year time span for short range planning is adequate because most telecommunications equipment can be obtained within the three year lead time allowed by the forecast.

Unit construction cost by arc is the basic input to the master program. Therefore a carrier company can readily adopt their present system for calculating the construction unit costs to the total system.

There are several additional factors that should be incorporated into the system to make the model more effective, such as:

a) sensitivity analysis regarding such factors as inflation, technology etc.,

b) checks and balances that will signal significant errors with respect to the input data, and

c) a tracking system that will insure a continual update of all input parameters.

Perhaps, most important of all, the model has to be operated by trained personnel who are technically competent and fully understand each sub-system within the model to maintain the integrety of the total system and avoid errors in the input data that could prove costly. Under these conditions the model can contribute significantly to the overall savings possible from an effective capital budgeting system.

5.1 Topics for Further Study

There are several areas with respect to the development of a total optimization system that require further comprehensive studies. The following represent some of the areas that should be of major concern.

1. A study to develop cost functions for switching equipment, exchange trunks, toll trunks etc. Extension of this model to cover these areas is necessary for optimization of the total telecommunication network.

2. Sensitivity studies with respect to;

   a) plant technology,

   b) urban area size,

   c) geographic area, and

   d) varying demand are desirable.

3. Further investigation into the effect of technology on investment decisions and the development of survivor curves for specific technologies (e.g. for fiber optics, radio system etc.).

4. Integrating the various models to arrive at a just and reasonable rate structure for the telecommunication system under study represents an in-depth analysis.

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APPENDIX A :THE COST MODEL COMPUTER PROGRAM

This program is a subroutine of the total optimization system. The program, written in FOTRAN IV, was run on an AMDHAL 470 V/6 machine at the University of Alberta Computing Services.This program run in conjunction with the input conversion system, master control unit(PNET program) and the output conversion system will give the near optimal plant layout and the capital budgeting information, including the construction program by switching center area. The cost model contains eight subprograms, namely MAINT, FCOST, CODE, EXCOST, NEWSIZ, TECH, GAREA, and AVCOST in addition to the main program.

The glossary of the variables used in the program is explained below, followed by the computer listing of the program.

A.1 Glossary of the Variables

CAP1 An integer referring to the lower capacity of the plant in an arc.

CAP2 An integer referring to the upper capacity of the plant ir an arc. This is a variable.

B A variable used to refer to the first cost.

CODARC(J) A code used to refer to the size of plant used in an arc. This code is assembled inside the

cost model for describing a particular arc. It is an eight digit code which has three parts: the first part contains one digit, the second contains three digits and the last part has four digits. The first part refers to the code specifying the class of plant, ITYPE. Part two contains the number of poles needed in the case of aerial cable, the size and number of ways of conduit used in the case of underground cable, and zero values in the case of buried cable plant. The third part contains the describtion of the cable used ; one digit for the major category of the cable (1-stalpeth, 2-alpeth etc.),the next digit for the gauge of cable used (1 for gauge 26, 2 for gauge 24,3 for gauge 22, 4 for gauge 19), and the last two digits are for the size of the cable (01 for 11 pair, 02 for 25 pair and so on).

COIL — A variable used to account for the number of loadings coils used in the arc considered.

CONCOS(I,J) — A variable referring to the cost of conduit . The cost are stored in a matrix referred to by the size and number of ways of the conduit.

COSTL — A variable to denote the labor cost.

COSTM — A variable to denote the material cost.

CTF — The capital tax factor.

DFACTO(I,J)

Difficulty rating matrix (a 7X4 matrix)

DLCOST(I) Total direct labor cost by function performed (an 8 row matrix).

DLRATE(I) The direct labor rate by craft type. (a 5 row matrix).

DLRMAT(I,J)

Components of the direct labor wage payment for the differnt types of craft (a 5X5 matrix).

DRTIME(I) Direct labor time by function performed (an 8 row matrix).

DRZ(I) Depreciation rate applicable to each type of plant (a 9 column matrix).

EQUIPM

(I,J,K,L) A variable representing the cost of any additional equipment required at the nodes of the arc in installing the cable plant. (If necessary the cable splicing equipment can be included in this category).

FUNPER(I,J) A matrix containg the time elements to do a particular function.

GAUGE(I) Refers to the airline distance of the beginning node I of the arc IJ, from the switching center.

GFMAIN Percentage growth in maintenance cost of a unit of plant as it ages. This is estimated by the maintenance department.

GSIZE(K) A variable used to refer to the gauge of the cable.

I	A variable used in the do-loops.
ID	The interest rate on debt capital.
IE	The interest rate on equity capital.
IF	The inflation rate .
IFREQ	The frequency of usage of a particular type of equipment .
IGAUGE	A variable counter used in choosing the gauge of the cable .
IIMAX	Maximum number of available cables of different sizes.
INTCPT(I, J,K)	The intercept of the regression line of cable cost per unit length versus the number of pairs.
ISPEC	A variable containing five digits and is used to refer to an arc, as explained below; the first digit =1 means the arc needs loading, =2 means the arc is non-loaded, the second digit =1 refers to stalpeth cable, =2 refers to alpeth cable,and the third, fourth and the fifth digits refer to the gauge of the cable, (e.g. 026).
ISTAL	A code to represent the different types of cable; 1-for stalpeth, 2-for alpeth.
ITYPE	Denotes the type of plant used in an arc. The number codes used for describing an the arc: 1 =underground paired cable, 2 =aerial paired cable,

	3 =buried paired cable,
	4 =underground coaxial cable,
	5 =aerial coaxial cable, and
	6 =buried coaxial cable.
IT	The technological growth rate.
J	A variable used in the do-loops.
KODARC	A code to refer to the size of the plant,(equivalent to CODARC).
KOIL	Refer to COIL.
LCINT	Average distance between loading coils.
LCCOIL	Number of different load coils considered.
LCCOST	Cost of load coils by type.
LLOAD(I,J)	Individual items of indirect labor loadings(a 6X4 matrix).
LPER	Length of each time period considered (normally one year).
LSUM(I)	Total labor loadings expressed as a percentage of the direct labor cost (a 4 row matrix).
MHCOST	The cost of construction of a manhole expressed for different types of manholes considered.
MHOLE	Number of different types of manhole or vaults.
NCALL	A counter to keep track of the number of times the cost model was called.
NCSIZE	The number of different sizes of conduits available.
NGAUGE	The maximum number of gauges of all the cables considered .

NGMAX	The maximum number of gauges of a particular kind of cable that is available.
NN	The planning horizon (normally 30 years).
NNEX(I)	The remaining useful life of the existing plant , expressed for each category of plant.
NPER	The number of periods considered in the planning period.
NSIZE	Number of different sizes of cable that is available.
NUMDIS	The number of resistance limiting distances.
NOWAY(I,J)	The number of ways of conduits for each different sizes of conduits available.
NUMWAY	The number of number of ways of conduits that can be installed.
OHLOAD(I)	The overall loading on the combined direct material and direct labor costs.This is divided into four groups.
OHPERC	Total loading on direct labor and direct material costs, expressed as a percentage.
OPCOST(I,J)	The operating cost by year for the different categories of plant.
PARA	The parameter 'A' in the technology assessment curve.
PARAFO	The parameter 'f(0)' in the technology assessment curve. This will be equated to one in the first period , in order to express the other values interms of this base index.

PARK	The parameter 'k' in the technology assessment curve.
PAIRS(I)	The number of pair count in the cable considered.
PEC	The present equivalent cost.
PMC	The present equivalent of maintenance cost factor.(p/c factor)
PRCENT(I,J)	Percentage work contribution by each craft for different category of function performed.
PRICE(I)	The prices of cables stored in an array.
POLCOS	Average cost of a pole.
POLDIS	Average distance between two poles.
RD	The debt equity ratio.
SIZE(I, J,K,L)	It is a four dimensional array that refers to the cable size (L), to the type of plant (I), the type of cable(J), and to the gauge(K).
SLOPE(I,J,K)	The slope of the regression line.(cost per meter against the number of pairs of cable)
SPEC(I,M,N)	It is an array containing the code ITYPE and the limiting loading distances for various types of plant. It is a three dimensional array.
TINDEX(I)	The ordinates of the 'S' curve in various years.
TIME	A variable representing the different years.
TOTCOS(I)	The total wage payment from the payroll information.

TT	The effective tax rate.
UNCOST(I,J)	A 2x3 matrix containing the construction costs for the arc under consideration. It stores the cost in three categories: cost of loading, cost of conduiting/poles, and cost of cabling.
UNKOST(I,J)	Similiar to the above variable.
VNNEX(I)	Salvage value of the existing classes of plant at the end of their useful life.
VO(I)	Current salvage value of the existing plant.

Table A.1 The Cost Model Computer Program.

```
C***********COST MODEL COMPUTER PROGRAM***********
C THIS PROGRAM CALCULATES THE ARC COST IN ANY GIVEN
C NODE.
C
C DIMENSION THE ARRAYS USED IN THE PROGRAM.
C THE REAL VARIABLES ARE DECLARED FIRST, FOLLOWED
C BY THE INTEGER VARIABLES.
C
      SUBROUTINE COST(IGEO,DIST,ITYPE,CAP1,CAP2,NYEAR,
     %GAUGE,LINES,ITECH,ICOST)
      REAL DLRMAT(5,5),TOTCOS(5),DLRATE(5),TMANHR(5),
     %FUNPER(8,5),DRTIME(8),PRCENT(5,8),DLCOST(8),
     %LLOAD(6,4),MLOAD(6,4),LSUM(6),MSUM(6),
     %SLOPE(6,3,5),INTCPT(6,3,5),EQUIPM(6,2,4,40),
     %MHCOST,LCCOST(6),CONCOS(5,6),OHLOAD(4),IT(5),
     %IE,ID,IF,IA(5),CTF(5,9),PEF(5),PMC(5),PPEF(5),
     %UNDEP(9),OPCOST(5,9),SPEC(6,2,10),VO(9),
     %DIAMTR(50),PERSAL(9),COIL(2),UNCOST(2,3),
     %KOIL,UNKOST(3),FACTOR(5),DFACTO(7,4),
     %SIZE(6,2,4,40),TINDEX(5),DRZ(9),BV(9)
     %,VNNEX(9),PRICE(50),TIME(5)
C
C
      INTEGER NOWAY(5,10),LIMIT(5),CAP1,CAP2,QTY(9),
     %NUMLIN(6),
     %NNEX(6),GSIZE(5),CODARC(2),PAIRS(35)
C
C THE COMMON BLOCKS ARE DECLARED BELOW.
C
      COMMON /F/KODARC,KOIL,UNKOST//NCALL,NUMDIS,SPEC,
     %TT,TINDEX,PPEF,PEF,NPER,TIME
     %/A/DFACTO
     %/B/PARAFO,PARA,PARK
     %/C/NSIZE,SIZE
     %/D/VO,VNNEX
     %/E/CODARC,COIL,UNCOST
     %/G/LCINT,POLDIS
     %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,NCSIZE,LIMIT
     %,CONCOS,MHCOST,INTCPT,SLOPE,EQUIPM,POLCOS,NGAUGE,GSIZE
     %/J/OPCOST,GFMAIN,NNEX,PMC,IA
     %/K/CTF
     %/L/PAIRS
C
C INITIALIZE THE VARIABLES.
C
      ICOMP=0
      DO 1800 LP=1,2
      CODARC(LP)=0
      COIL(LP)=0.
```

```
      DO 1801 MP=1,3
      UNCOST(LP,MP)=0.
1801  CONTINUE
1800  CONTINUE
C UPDATE THE NUMBER OF TIMES THIS PROGRAM WAS CALLED.
C
      NCALL=NCALL+1
C IF CALLING FOR THE SECOND TIME OR MORE SKIP THE
C CALCULATION OF DIRECT LABOR COST,DIRECT LABOR
C RATES etc.
      IF(NCALL.GT.1) GO TO 100
C READ THE PLANNING HORIZON, LENGTH OF PLANNING
C PERIODS.
      READ(1,6)NPER
      DO 1401 KK=1,NPER
      READ(1,6) LPER
      IF(KK.NE.1)GO TO 1402
      TIME(1)=FLOAT(LPER)
      GO TO 1401
C ADVANCE THE TIME TO INDICATE THE CORRECT PERIOD.
1402  TIME(KK)=TIME(KK-1)+FLOAT(LPER)
1401  CONTINUE
C READ THE WAGES, FRINGE BENIFITS etc. FOR CALCULATION
C OF DIRECT LABOR COST.
      READ(1,1) ((DLRMAT(I,J),J=1,5),I=1,5)
1     FORMAT(5F10.2)
      DO 1000 I=1,5
      TOTCOS(I)=0.0
      DLRATE(I)=0.0
      DO 1001 J=1,5
C CALCULATE THE TOTAL WAGE PAYMENT.
      TOTCOS(I)=TOTCOS(I)+DLRMAT(I,J)
1001  CONTINUE
C READ THE DIRECT MANHOURS BY EACH CRAFT, AND THE
C PRODUCTIVITY FACTOR OF EACH CRAFT.
      READ(1,1)TMANHR(I),FACTOR(I)
      TMANHR(I)=TMANHR(I)*FACTOR(I)
      IF(TMANHR(I).EQ.0)GO TO 1000
C FIND THE DIRECT LABOR RATE BY CRAFT TYPE.
      DLRATE(I)=TOTCOS(I)/TMANHR(I)
1000  CONTINUE
      DO 1002 I=1,8
C READ  THE DIRECT LABOR TIME TO PERFORM DIFFERENT
C FUNCTIONS.
      READ(1,2) (FUNPER(I,J),J=1,5)
2     FORMAT(5F10.4)
      DRTIME(I)=0.0
      DO 1003 K=1,5
      DRTIME(I)=DRTIME(I)+FUNPER(I,K)
1003  CONTINUE
1002  CONTINUE
C
C CALCULATE DIRECT LABOR COST BY FUNCTION PERFORMED.
C
```

```
      READ(1,3)((PRCENT(I,J),J=1,8),I=1,5)
3     FORMAT(8F10.8)
      DO 1004 I=1,8
      DLCOST(I)=0.0
      DO 1005 J=1,5
      DLCOST(I)=DLCOST(I)+PRCENT(J,I)*DLRATE(J)
1005  CONTINUE
      DLCOST(I)=DLCOST(I)*DRTIME(I)
1004  CONTINUE
      READ(1,4)((DFACTO(I,J),J=1,4),I=1,7)
4     FORMAT(4F10.2)
C
C CALCULATE DIRECT LABOR LOADINGS, DIRECT MATERIAL
C LOADINGS.
C
      READ(1,5)((LLOAD(I,J),MLOAD(I,J),J=1,4),I=1,6)
5     FORMAT(8F10.2)
      DO 2105 I=1,6
      LSUM(I)=0.
      MSUM(I)=0.
      DO 1006 J=1,4
      LSUM(I)=LSUM(I)+LLOAD(I,J)
      MSUM(I)=MSUM(I)+MLOAD(I,J)
1006  CONTINUE
2105  CONTINUE
C
C READ THE CABLE DATA : THE NUMBER OF PAIRS,THE GAUGES
C OF CABLE AVAILABLE, AND THEIR PRICE.
      READ(1,6)NGAUGE
      DO 1201 K=1,NGAUGE
      READ(1,6)GSIZE(K)
1201  CONTINUE
      READ(1,6)NSIZE
      READ(1,40)(PAIRS(L),L=1,NSIZE)
40    FORMAT(20I4)
      DO 1507 I=1,6
      READ(1,6)ISTAL
      IF(ISTAL.EQ.0)GO TO 1507
      READ(1,6)NUMDIS
      IF(NUMDIS.EQ.0)GO TO 1507
      DO 1018 N=1,NUMDIS
C
C READ THE CABLE DESIGN SPECIFICATIONS.
C
      READ(1,14)(SPEC(I,M,N),M=1,2)
14    FORMAT(F10.2,F5.0)
1018  CONTINUE
6     FORMAT(I3)
      DO 1607 J=1,ISTAL
      READ(1,6)NGMAX
      IF(NGMAX.EQ.0)GO TO 1607
      DO 1007 K=1,NGAUGE
      READ(1,6)IIMAX
      IF(IIMAX.EQ.0)GO TO 1007
```

```
      DO 1403 II=1,IIMAX
C
C READ CABLE SIZES,PRICEAND ANY OTHER ADDITIONAL
C EQUIPMENT NEEDED ALONG WITH THE CABLES.
      READ(1,4)SIZE(I,J,K,II),PRICE(II),EQUIPM(I,J,K,II)
1403  CONTINUE
C
C DO THE REGRESSION AND FIND THE SLOPE AND THE INTERCEPT
C OF ALL THE CABLES CONSIDERED. STORE THESE VALUES.
C
      MSIZE=0.
      SUMX=0.
      SUMY=0.
      SUMXY=0.
      SUMX2=0.
      DO 1008 ISIZE=1,IIMAX
      IF(PRICE(ISIZE).EQ.0)GO TO 1008
      MSIZE=MSIZE+1
      SUMX=SUMX+SIZE(I,J,K,ISIZE)
      SUMY=SUMY+PRICE(ISIZE)
      SUMXY=SUMXY+SIZE(I,J,K,ISIZE)*PRICE(ISIZE)
      SUMX2=SUMX2+SIZE(I,J,K,ISIZE)*SIZE(I,J,K,ISIZE)
1008  CONTINUE
      SLOPE(I,J,K)=(SUMXY-(SUMX*SUMY)/MSIZE)/
     %(SUMX2-((SUMX*SUMX)/MSIZE))
      INTCPT(I,J,K)=(SUMY-SLOPE(I,J,K)*SUMX)/MSIZE
1007  CONTINUE
C
1607  CONTINUE
1507  CONTINUE
C
C
C READ THE MANHOLE COST,  THE CONDUIT COST, AND THE
C LOADING COIL COST.
      READ(1,6)MHOLE
      MHCOST=AVCOST(MHOLE)
      READ(1,7)LCINT
      DO 1024 I=1,6
      READ(1,6)LCCOIL
1024  LCCOST(I)=AVCOST(LCCOIL)
      READ(1,7)NCSIZE
7     FORMAT(2I6)
      DO 1009 I=1,NCSIZE
      READ(1,7)LIMIT(I),NUMWAY
      READ(1,8)(NOWAY(I,J),CONCOS(I,J),J=1,NUMWAY)
8     FORMAT(I3,F10.2)
1009  CONTINUE
      READ(1,31)POLCOS,POLEQ,POLDIS
31    FORMAT(3F10.2)
      READ(1,1)(OHLOAD(I),I=1,4)
      OHPERC=0.
      DO 1010 I=1,4
1010  OHPERC=OHPERC+OHLOAD(I)
C
```

```
C READ THE FINANCIAL DATA: TAX RATE,DEBT RATIO,INTEREST
C ON EQUITY,INTEREST ON DEBT, AND THE INFLATION RATE.
C
      READ(2,9)TT,RD,IE,ID,IF
9     FORMAT(5F10.5)
C READ THE PLANNING HORIZON , THE DEPRECIATION RATE
C BY TYPE OF PLANT, SALVAGE VALUE BY TYPE OF PLANT
C IN THE CASE OF NEWLY INSTALLED PLANT.
      READ(2,10)NN,(DRZ(I),I=1,9)
      READ(2,22)(PERSAL(I),I=1,9)
10    FORMAT(I3,/,9F5.3)
C
C READ THE TECHNOLOGY CURVE PARAMETERS AND THE GROWTH
C FACTOR ATTRIBUTABLE TO MAINTENANCE COST.
C
      READ(2,11)PARAFO,PARA,PARK,GFMAIN
11    FORMAT(4F10.5)
C CALCULATE THE TECHNOLOGY INDEX FOR VARIOUS YEARS FROM
C THE TECHNOLOGY CURVE.
      DO 1011 I=1,NPER
      TINDEX(I)=TECH(TIME(I))
      IT(I)=1.-EXP(ALOG(TECH(TIME(I)+FLOAT(NN))
     %/TECH(TIME(I)))
     %/FLOAT(NN))
C
C CALCULATE THE MINIMUM ATTRACTIVE RATE OF RETURN.
      IA(I)=(1.-RD)*((1.+IE)*(1.+IF)*(1.-IT(I))-1.)
     %+(1.-TT)*RD*ID
      DO 1012 J=1,9
C
C CALCULATE THE CAPITAL TAX FACTOR.
      CTF(I,J)=1.-(TT*DRZ(J))/(IA(I)+DRZ(I))
1012  CONTINUE
C
C FIND THE PARTIAL PRESENT EQUIVALENT OF FUTURE SUM AND
C THE PRESENT EQUIVALENT OF A FUTURE SUM FACTORS.
      PPEF(I)=1./((1.+IA(I))**NN)
      PEF(I)=1./((1.+IA(I))**TIME(I))
C
C COMPARE THE GROWTH RATE OF MAINTENANCE COST WITH THE
C MARR AND CALCUALTE THE APPROPRIEATE PRECENT EQUIVALENT
C OF MAINTENANCE COST FACTORS.
C
      IF(GFMAIN-IA(I))1013,1014,1015
C
1013  X=(1.+IA(I))/(1.+GFMAIN)-1.
      PMC(I)=(1./(1.+GFMAIN))*((1.+X)**NN-1.)/(X*((1.+X)
     %**NN))
      GO TO 1011
1014  PMC(I)=NN/(1.+IA(I))
      GO TO 1011
1015  X=(1.+GFMAIN)/(1.+IA(I))-1.
      PMC(I)=(1./(1.+IA(I)))*((1.+X)**NN-1.)/X
1011  CONTINUE
```

```
C
CIN THE CASE OF THE EXISTING PLANT READ THE LIFE OF EACH
C CATEGORY OF PLANT, THE PRESENT SALVAGE VALUE, AND FUTURE
C SALVAGE AT RETIREMENT.
C
13    FORMAT(6I10)
      READ(2,13) (NNEX(I),I=1,6)
      READ(2,22) (VNNEX(I),I=1,9)
C READ THE ANTICIPATED OPERATING COST PER UNIT SIZE OF
C PLANT FOR A VINTAGE INSTALLED IN THE FIRST , SECOND,
C THIRD, FOURTH PERIODS RESPECTIVELY BY EACH CATEGORY
C OF PLANT.
      NPER1=NPER+1
      DO 1023 I=1,NPER1
      READ(2,22) (OPCOST(I,J),J=1,9)
22    FORMAT(5F10.2,/,4F10.2)
1023  CONTINUE
100   KTYPE=ITYPE
C COMPARE 1.27 TIMES THE AIRLINE DISTANCE WITH THE
C LOADING LIMIT DISTANCES, AND SELECT THE PROPER
C CABLE.
      DIST2=1.27*GAUGE+DIST
      DO 1021 I=1,NUMDIS
      IF(DIST2.LE.SPEC(KTYPE,1,I))GO TO 1022
1021  CONTINUE
C IF NONE OF THE AVAILABLE CABLES IS WITHIN THE
C RESISTANCE LIMIT DISTANCE OUTPUT A SIGNAL.
      WRITE(6,21)
21    FORMAT('ENDING NODE OUT OF RANGE')
      STOP
C SELECTING THE PROPER GAUGE OF THE CABLE.
1022  ISPEC=IFIX(SPEC(KTYPE,2,I))
      JSPEC=MOD(ISPEC,10000)/1000
      JGAUGE=MOD(ISPEC,1000)
      DO 3000 IGAUGE=1,NGAUGE
      IF(GSIZE(IGAUGE).EQ.JGAUGE)GO TO 3001
3000  CONTINUE
3001  KSPEC=IGAUGE
      IF(CAP1.NE.CAP2)GO TO 1019
      IF(CAP1.EQ.0)GO TO 1020
C IN THE CASE OF THE EXISTING PLANT, CALCULATE THE
C PRESENT EQUIVALENT OF MAINTENANCE COST AND THE
C CAPITAL COST OF THE EXISTING PLANT.
      CALL MAINT(10,KTYPE,CAP1,CAP2,0,DIST,ISPEC,LINES,PEM)
      CALL EXCOST(10,KTYPE,CAP1,CAP2,0,DIST,ISPEC,B,V)
C
C
C
C
C CALCULATE THE PRESENT EQUIVALENT COST OF THE PLANT.
C
C
      PEC=PEM+(B-(V/((1.+IA(1))**NNEX(KTYPE))))/(1.-TT)
C FIND THE UNIT COST(IN CENTS) OF THE ARC BY DIVIDING
```

```
C BY THE FLOW IN THE ARC.
      ICOST=IFIX(PEC*100./FLOAT(CAP1))
      RETURN
C
C
1020  CAP1=SIZE(ITYPE,JSPEC,KSPEC,1)
      CAP2=CAP1
      CALL MAINT(20,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(20,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
C EVALUATE THE CODE OF THE CABLE SELECTED AND ITS COST.
      CALL CODE(1,KODARC,KOIL,UNKOST)
      GO TO 1100
1019  IF(CAP1.EQ.0)GO TO 1030
      IF(CAP2.EQ.0)GO TO 1031
C UPDATING THE NON-PRIMARY ARC FOR THE SECOND TIME.
      CALL MAINT(31,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(31,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
      GO TO 1100
C UPDATING THE PRIMARY ARC, FOR THE FIRST TIME.
1030  CAP2=NEWSIZ(ITYPE,JSPEC,KSPEC,CAP2)
      CALL MAINT(21,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(21,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
      IF(MOD(KTYPE,3).EQ.1)GO TO 1100
      ICOMP=1
      CALL MAINT(21,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM2)
      CALL FCOST(21,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B2,V2)
      CALL CODE(2,KODARC,KOIL,UNKOST)
      GO TO 1100
C UPDATING THE NON-PRIMARY ARC FOR THE FIRST TIME.
1031  CAP2=NEWSIZ(ITYPE,JSPEC,KSPEC,CAP1+1)
      CALL MAINT(30,KTYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
      CALL FCOST(30,KTYPE,CAP1,CAP2,NYEAR,DIST,LINES
     %,ISPEC,IGEO,B,V)
      CALL CODE(1,KODARC,KOIL,UNKOST)
C
1100  PEC=(PEM+TINDEX(NYEAR)*(B-V*PPEF(NYEAR))/(1.-TT))
     %*PEF(NYEAR)
      IF(ICOMP.EQ.0)GO TO 1200
C
C
C
      PEC2=(PEM2+TINDEX(NYEAR)*(B2-V2*PPEF(NYEAR))/(1.-TT))
     %*PEF(NYEAR)
```

```
      IF(PEC-PEC2) 1200,1200,1105
1105  ITYPE=KTYPE
      PEC=PEC2
      CODARC(1)=CODARC(2)
      COIL(1)=COIL(2)
      DO 1220 IL=1,3
1220  UNCOST(1,IL)=UNCOST(1,IL)
1200  IF(CAP2.EQ.CAP1) GO TO 1700
      ICOST=IFIX(PEC*100./FLOAT(CAP2-CAP1))
      RETURN
1700  ICOST=IFIX(PEC*100./FLOAT(CAP1))
      RETURN
      END
C
C **********SUBROUTINE MAINT***************************
C
C THIS SUBROUTINE CALCULTES THE PRESENT EQUIVALENT OF
C MAINTENANCE COST FOR EXISTING PLANT AND NEWLY
C INSTALLED PLANT.
      SUBROUTINE MAINT(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST,ISPEC
     %,LINES,PEM)
C DECLARATION OF VARIABLES.
      REAL OPCOST(5,9),IA(5),PMC(5)
      INTEGER NNEX(6)
      COMMON/G/LCINT,POLDIS/J/OPCOST,GFMAIN,NNEX,PMC
     %,IA
      INTEGER CAP1,CAP2,CAP
C INITIALIZE PEM.
      PEM=0
      NYEAR=NYEAR+1
      CAP=CAP2
      IF((KODE/10).EQ.3)CAP=CAP2-CAP1
C CALCULATE THE PEM FOR MISCELLENEOUS  EQUIPMENT.
C IF CALCULATING FOR THE NON-PRIMARY ARC ONLY THE
C INCREMENTAL PEM IS TO BE CALCULATED.
      IF((ISPEC/10000).EQ.1)PEM=PEM+OPCOST(NYEAR,9)*(DIST
     %/FLOAT(LCINT))
      IF(MOD(ITYPE,3).NE.1)GO TO 2
      IF(KODE.NE.10)GO TO 21
C CALCULATE PEM FOR DUCTS AND VAULTS.
      PEM=PEM+OPCOST(NYEAR,7)*LINES*DIST
      GO TO 22
21    IF(LINES*100.GE.CAP)GO TO 23
C CALCULATE PEM FOR CABLES.
22    PEM=PEM+OPCOST(NYEAR,7)*DIST
23    PEM=PEM+OPCOST(NYEAR,6)*DIST*CAP
      IF(ITYPE.EQ.4)PEM=PEM+(OPCOST(NYEAR,4)-OPCOST(NYEAR,6
     %))*DIST*CAP
      GO TO 10
2     IF(MOD(ITYPE,3).NE.0)GO TO 3
      PEM=PEM+OPCOST(NYEAR,4)*DIST*CAP
      IF(ITYPE.EQ.6)PEM=PEM+(OPCOST(NYEAR,5)-OPCOST(NYEAR,4
     %))*DIST*CAP
      GO TO 10
```

```
3       IF(KODE.EQ.10)GO TO 24
        IF(LINES*100.GE.CAP)GO TO 25
24      PEM=PEM+OPCOST(NYEAR,2)*(DIST/POLDIS)
25      PEM=PEM+OPCOST(NYEAR,1)*DIST*CAP
        IF(ITYPE.EQ.5)PEM=PEM+(OPCOST(NYEAR,3)-OPCOST(NYEAR,1
       %))*DIST*CAP
10      NYEAR=NYEAR-1
        IF(NYEAR.NE.0)GO TO 11
C COMPARE THE GROWTH FACTOR IN MAINTENANCE WITH MARR
C AND CALCULATE THE APPROPRIEATE PEM FACTOR.
        IF(GFMAIN-IA(1))4,5,6
4       X=(1.+IA(1))/(1.+GFMAIN)-1.
        PEM=(1./(1.+GFMAIN))*((1.+X)**NNEX(ITYPE)-1.)/
       %(X*((1.+X)**NNEX(ITYPE)))*PEM
        GO TO 7
5       PEM=(NNEX(ITYPE)/(1.+IA(1)))*PEM
        GO TO 7
6       X=(1.+GFMAIN)/(1.+IA(1))-1.
        PEM=PEM*((1./1.+IA(1)))*((1.+X)**NNEX(ITYPE)-1.)/X
7       RETURN
11      PEM=PEM*PMC(NYEAR)
        RETURN
        END
C
C ************SUBROUTINE FCOST***********8******
C
C THIS SUBROUTINE CALCULATES THE FIRST COST OF NEWLY
C INSTALLED PLANT. IT CALCULATES THE LABOR COST, MATERIAL
C COST AND ANDS THE OVERHEADS TO THEM.
        SUBROUTINE FCOST(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST,LINES
       %,ISPEC,IGEO,B,V)
        REAL CTF(5,9),LCCOST(6),PERSAL(9),DLCOST(8)
       $,MSUM(6),CONCOS(5,6),MHCOST,INTCPT(6,3,5),SLOPE(6,3,5)
       %,EQUIPM(6,2,4,40),SIZE(6,2,4,40),UNCOST(3),LSUM(6)
        DIMENSION OLDCOS(3)
        INTEGER CODARC,GSIZE(5),CAP1,CAP2,LIMIT(5),PAIRS(35)
        COMMON/C/NSIZE,SIZE/G/LCINT,POLDIS
       %/F/CODARC,COIL,UNCOST
       %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,
       %NCSIZE,LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,
       %EQUIPM,POLCOS,NGAUGE,GSIZE
       %/K/CTF/L/PAIRS
        COSTL=0.
        COSTM=0.
        DO 2 I=1,3
2       UNCOST(I)=0.
        COIL=0.
        CODARC=0
        KOUNT=0
        B=0.
        VM=0.
        VL=0.
        JSPEC=MOD(ISPEC,10000)
        KSPEC=MOD(ISPEC,1000)
```

```
      JSPEC=JSPEC/1000
      DO 11 IG=1,NGAUGE
      IF(KSPEC.EQ.GSIZE(IG))GO TO 12
11    CONTINUE
12    KSPEC=IG
20    DO 13 ICAP=1,NSIZE
      IF(CAP1.EQ.PAIRS(ICAP))GO TO 14
13    CONTINUE
14    MSPEC=ICAP
      CODARC=ITYPE*10000000
      CODARC=CODARC+JSPEC*1000+KSPEC*100+MSPEC
      DO 2222 ICAP=1,40
      IF(CAP1.EQ.SIZE(ITYPE,JSPEC,KSPEC,ICAP))GO TO 2223
2222  CONTINUE
2223  MSPEC=ICAP
      IF((ISPEC/10000).NE.1)GO TO 22
      COSTM=COSTM+LCCOST(ITYPE)*CTF(NYEAR,9)*DIST
     %/FLOAT(LCINT)
      VM=VM+COSTM*PERSAL(9)
      COSTL=COSTL+DLCOST(8)*DIST/FLOAT(LCINT)
      VL=VL+COSTL*PERSAL(9)
      COIL=(DIST/FLOAT(LCINT))
      UNCOST(1)=(COSTL*(1.+LSUM(ITYPE)/100.)
     %+COSTM*(1.+MSUM(ITYPE)/100.))*(1.+OHPERC/100.)
22    IF(MOD(ITYPE,3).NE.1)GO TO 6
      IF((LINES*100).GE.CAP1)GO TO 7
      NCAP1=CAP1-LINES*100
      DO 8 I=1,NCSIZE
      IF(LIMIT(I).LT.NCAP1)GO TO 8
      J=1
      GO TO 9
8     CONTINUE
C
C
C
      I=NCSIZE
      J=NCAP1/LIMIT(NCSIZE)
      IF(MOD(NCAP1,LIMIT(NCSIZE)).NE.0)J=J+1
9     COSTM1=(CONCOS(I,J)*DIST+MHCOST)
      COSTM=COSTM+COSTM1*CTF(NYEAR,7)
      VM=VM+COSTM1*PERSAL(7)
      CODARC=CODARC+I*1000000+J*10000
      UNCOST(2)=COSTM1*(1.+MSUM(ITYPE)/100.)+UNCOST(2)
      CALL GAREA(IGEO,3,GFACTO)
      COSTL1=(DLCOST(3)*GFACTO)*DIST
      COSTL=COSTL+COSTL1*CTF(NYEAR,7)
      VL=VL+COSTL1*PERSAL(7)
      UNCOST(2)=COSTL1*(1.+LSUM(ITYPE)/100.)+UNCOST(2)
      CALL GAREA(IGEO,5,GFACTO)
      COSTL1=(DLCOST(5)*GFACTO)*DIST
      COSTL=COSTL+COSTL1*CTF(NYEAR,7)
      VL=VL+COSTL1*PERSAL(7)
      UNCOST(2)=COSTL1*(1.+LSUM(ITYPE)/100.)+UNCOST(2)
7     JDEP=((ITYPE+5)/ITYPE)*ITYPE
```

```
      CALL GAREA(IGEO,4,GFACTO)
      COSTL1=DLCOST(4)*GFACTO*CAP1
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+(1.+LSUM(ITYPE)/100.)*COSTL1
C
      IF(ITYPE.EQ.4)GO TO 10
      COSTM1=(INTCPT(1,JSPEC,KSPEC)+(SLOPE(1,JSPEC,KSPEC)*
     %CAP1))*DIST+EQUIPM(1,JSPEC,KSPEC,MSPEC)
      COSTM=COSTM+COSTM1*CTF(NYEAR,6)
      VM=VM+COSTM1*PERSAL(6)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
      GO TO 15
 10   COSTM1=((INTCPT(4,JSPEC,KSPEC)+SLOPE(1,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(4,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,8)
      VM=VM+COSTM1*PERSAL(8)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
 15   COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      COSTL=COSTL*(1.+LSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=(COSTM+COSTL)*(1.+OHPERC/100.)
      V=(VM+VL)*(1.+OHPERC/100.)
      GO TO 5
 6    IF(MOD(ITYPE,3).EQ.0)GO TO 16
      IF((LINES*100).GE.CAP1)GO TO 17
      NOPOLE=IFIX(DIST/POLDIS)
      IF((FLOAT(NOPOLE)*POLDIS).NE.DIST)NOPOLE=NOPOLE+1
      CODARC=NOPOLE*10000
      COSTM1=FLOAT(NOPOLE)*POLCOS*(1.+POLEQ/100.)
      COSTM=COSTM+COSTM1*CTF(NYEAR,2)
      VM=VM+COSTM1*PERSAL(2)
      UNCOST(2)=UNCOST(2)+COSTM1*(1.+MSUM(ITYPE)/100.)
      CALL GAREA(IGEO,1,GFACTO)
      COSTL=GFACTO*FLOAT(NOPOLE)*DLCOST(1)
C
C
C
      COSTL=COSTL+COSTL1*CTF(NYEAR,2)
      VL=VL+COSTL1*PERSAL(2)
      UNCOST(2)=UNCOST(2)+COSTL1*(1.+LSUM(ITYPE)/100.)
 17   CALL GAREA(IGEO,1,GFACTO)
      JDEP=((ITYPE/2)+MOD(ITYPE,2))
      COSTL1=(DLCOST(2)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      IF(ITYPE.EQ.5)GO TO 18
      COSTM1=((INTCPT(2,JSPEC,KSPEC)+SLOPE(2,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(2,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,1)
      VM=VM+COSTM1*PERSAL(1)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
```

```
      GO TO 19
18    COSTM1=((INTCPT(5,JSPEC,KSPEC)+SLOPE(5,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(5,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,3)
      VM=VM+COSTM1*PERSAL(3)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
19    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      COSTL=COSTL*(1.+LSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=(COSTM+COSTL)*(1.+OHPERC/100.)
      V=(VM+VL)*(1.+OHPERC/100.)
      GO TO 5
16    JDEP=5-MOD(ITYPE,2)
      CALL GAREA(IGEO,6,GFACTO)
      COSTL1=(DLCOST(6)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      CALL GAREA(IGEO,7,GFACTO)
      COSTL1=(DLCOST(7)*GFACTO)
      COSTL=COSTL+COSTL1*CTF(NYEAR,JDEP)
      VL=VL+COSTL1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTL1*(1.+LSUM(ITYPE)/100.)
      COSTM1=(INTCPT(ITYPE,JSPEC,KSPEC)+SLOPE(ITYPE,
     %JSPEC,KSPEC)*CAP1*DIST+EQUIPM(ITYPE,JSPEC,
     %KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,JDEP)
      VM=VM+COSTM1*PERSAL(JDEP)
      UNCOST(3)=UNCOST(3)+COSTM1*(1.+MSUM(ITYPE)/100.)
      GO TO 19
C
C
C
5     IF(CAP1.EQ.CAP2)GO TO 3
      IF(KOUNT.NE.0)GO TO 21
      OLDCAP=CAP1
      OLDV=V
      CAP1=CAP2
      OLDB=B
      KOUNT=100
      DO 23 IL=1,3
      OLDCOS(IL)=UNCOST(IL)
      UNCOST(IL)=0.
23    CONTINUE
      CODARC=0
      GO TO 20
21    B=B-OLDB
      V=V-OLDV
      CAP1=OLDCAP
      DO 24 IL=1,3
      UNCOST(IL)=UNCOST(IL)-OLDCOS(IL)
24    CONTINUE
3     DO 25 IL=1,3
```

```
      UNCOST(IL)=UNCOST(IL)*(1.+OHPERC/100.)
25    CONTINUE
      RETURN
      END
C
C **********SUBROUTINE CODE*********************
C
C THIS SUBROUTINE UPDATES THE ARC CODE IN ORDER TO
C ASSIGN THE PROPER COST TO THE ARC CONSIDERED.
      SUBROUTINE CODE(NO,KODARC,
     %KOIL,UNKOST)
      DIMENSION UNCOST(2,3),COIL(2)
      INTEGER CODARC(2)
      REAL UNKOST(3),KOIL
      COMMON/E/CODARC,COIL,UNCOST
      CODARC(NO)=KODARC
      COIL(NO)=KOIL
      DO 1202 IL=1,3
1202  UNCOST(NO,IL)=UNKOST(IL)
      RETURN
      END
C
C
C
C
C ****************THE FUNCTION NEWSIZ***************
C
C THIS FUNCTION IS USED TO SELECT THE PROPER CABLE
C IN AN ORDER.
      FUNCTION NEWSIZ(ITYPE,JTYPE,KTYPE,ICAP)
C DECLARE THE VARIABLES.
      REAL SIZE(6,2,4,40)
      COMMON /C/NSIZE,SIZE
      DO 1 I=1,NSIZE
      IF(SIZE(ITYPE,JTYPE,KTYPE,I).GE.ICAP)GO TO 2
1     CONTINUE
C THE NEW SIZE OF THE CABLE IS SELECTED.
2     NEWSIZ=SIZE(ITYPE,JTYPE,KTYPE,I)
      RETURN
      END
C
C **************THE FUNCTION TECH****************
C THIS FUNCTION IS USED TO FIND THE TECHNOLOGICAL
C GROWTH FACTOR USING THE LOGISTICS CURVE.
      FUNCTION TECH(YEAR)
      COMMON /B/PARAFO,PARA,PARK
      NYEAR=IFIX(YEAR)
      TECH=PARAFO*(1.-(1./(1.+(PARA/EXP(PARK*FLOAT
     %(NYEAR))))))
      RETURN
      END
C
C ******************SUBROUTINE GAREA***************
C IT IS USED TO EVALUATE THE GEOGRAPHY DIFFICULTY
```

```
C FACTOR, DEPENDING ON THE GEOGRAPHICAL CONDITION
C OF THE ARC.
C
C
      SUBROUTINE GAREA(IGEO,ITEM,GFACTO)
      COMMON/A/DFACTO
      REAL DFACTO(7,4)
      INTEGER CODE(3)
      CODE(1)=IGEO/100
      CODE(2)=(MOD(IGEO,100))/10
      CODE(3)=MOD(IGEO,10)
      GFACTO=1.
      DO 2 J=1,3
      IF(CODE(J).EQ.0) GO TO 3
      GFACTO=GFACTO*DFACTO(ITEM,CODE(J))
2     CONTINUE
3     RETURN
      END
C
C *************THE FUNCTION AVCOST*****************
C THIS FUNCTION IS USED TO FIND THE WEIGHTED AVERAGE
C COST OF A MANHOLE OR ANY MISCELLENEOUS EQUIPMENTS.
C
      FUNCTION AVCOST(N)
      DIMENSION COST(30),IFREQ(30)
      READ(1,1)(COST(I),IFREQ(I),I=1,N)
1     FORMAT(F10.2,I10)
      TOTAL=0.
      SUM=0.
      DO 2 J=1,N
      SUM=SUM+COST(J)*FLOAT(IFREQ(J))
      TOTAL=TOTAL+FLOAT(IFREQ(J))
2     CONTINUE
      AVCOST=SUM/TOTAL
      RETURN
      END
C
C
C **************SUBROUTINE EXCOST**********************
C
C THIS SUBROUTINE IS USED TO FIND THE COST OF EXISTING
C PLANT.IT CONSIDERS THE LABOR COST AND ANY OTHER
C OVERHEADS THAT WERE INCURRED AT THE TIME OF
C INSTALLATION OF THE PLANT AS SUNK COST. ONLY
C CURRENT MATERIAL COST AFTER DEDUCTING A FIXED
C PERCENTAGE FOR THE COST OF REMOVAL IS RELEVENT
C IN MAKING ANY DECISIONS.
      SUBROUTINE EXCOST(KODE,ITYPE,CAP1,CAP2,NYEAR,DIST
     %,ISPEC,B,V)
      REAL CTF(5,9),LCCOST(6),PERSAL(9),DLCOST(8)
     $,MSUM(6),CONCOS(5,6),MHCOST,INTCPT(6,3,5),SLOPE(6,3,5)
     %,EQUIPM(6,2,4,40),SIZE(6,2,4,40),UNCOST(3),LSUM(6)
     %,VO(9),VNNEX(9)
      DIMENSION OLDCOS(3)
```

```
      INTEGER CODARC,GSIZE(5),CAP1,CAP2,LIMIT(5),PAIRS(35)
      COMMON/C/NSIZE,SIZE/G/LCINT,POLDIS
     %/H/LCCOST,PERSAL,DLCOST,LSUM,MSUM,OHPERC,
     %NCSIZE,LIMIT,CONCOS,MHCOST,INTCPT,SLOPE,
     %EQUIPM,POLCOS,NGAUGE,GSIZE
     %/K/CTF/D/VO,VNNEX
      COSTM=0.
      B=0.
      VM=0.
      JSPEC=MOD(ISPEC,10000)
      KSPEC=MOD(ISPEC,1000)
      JSPEC=JSPEC/1000
      DO 11 IG=1,NGAUGE
      IF(KSPEC.EQ.GSIZE(IG)) GO TO 12
11    CONTINUE
12    KSPEC=IG
      DO 2222 ICAP=1,40
      IF(CAP1.EQ.SIZE(ITYPE,JSPEC,KSPEC,ICAP)) GO TO 2223
2222  CONTINUE
2223  MSPEC=ICAP
      IF((ISPEC/10000).NE.1) GO TO 22
      COSTM=COSTM+LCCOST(ITYPE)*CTF(NYEAR,9)*DIST
     %/FLOAT(LCINT)
      VM=VM+COSTM*VNNEX(9)
22    IF(MOD(ITYPE,3).NE.1) GO TO 6
      DO 8 I=1,NCSIZE
      IF(LIMIT(I).LT.CAP1) GO TO 8
      J=1
      GO TO 9
8     CONTINUE
      I=NCSIZE
      J=CAP1/LIMIT(NCSIZE)
      IF(MOD(CAP1,LIMIT(NCSIZE)).NE.0) J=J+1
9     COSTM1=(CONCOS(I,J)*DIST+MHCOST)
      COSTM=COSTM+COSTM1*CTF(NYEAR,7)
      VM=VM+COSTM1*VNNEX(7)
      IF(ITYPE.EQ.4) GO TO 10
      COSTM1=(INTCPT(1,JSPEC,KSPEC)+(SLOPE(1,JSPEC,KSPEC)*
     %CAP1))*DIST+EQUIPM(1,JSPEC,KSPEC,MSPEC)
      COSTM=COSTM+COSTM1*CTF(NYEAR,6)
      VM=VM+COSTM1*VNNEX(6)
      GO TO 15
10    COSTM1=((INTCPT(4,JSPEC,KSPEC)+SLOPE(1,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(4,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,8)
      VM=VM+COSTM1*VNNEX(8)
15    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      VL=VL*(1.+LSUM(ITYPE)/100.)
      B=0.8*COSTM
      V=0.8*VM
      RETURN
6     IF(MOD(ITYPE,3).EQ.0) GO TO 16
      NOPOLE=IFIX(DIST/POLDIS)
```

```
      IF((FLOAT(NOPOLE)*POLDIS).NE.DIST) NOPOLE=NOPOLE+1
      COSTM1=FLOAT(NOPOLE)*POLCOS*(1.+POLEQ/100.)
      COSTM=COSTM+COSTM1*CTF(NYEAR,2)
      VM=VM+COSTM1*VNNEX(2)
      IF(ITYPE.EQ.5) GO TO 18
      COSTM1=((INTCPT(2,JSPEC,KSPEC)+SLOPE(2,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(2,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,1)
      VM=VM+COSTM1*VNNEX(1)
      GO TO 19
18    COSTM1=((INTCPT(5,JSPEC,KSPEC)+SLOPE(5,JSPEC,KSPEC)*
     %CAP1)*DIST+EQUIPM(5,JSPEC,KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,3)
      VM=VM+COSTM1*VNNEX(3)
19    COSTM=COSTM*(1.+MSUM(ITYPE)/100.)
      VM=VM*(1.+MSUM(ITYPE)/100.)
      B=0.8*COSTM
      V=0.8*VM
      RETURN
16    JDEP=5-MOD(ITYPE,2)
      COSTM1=(INTCPT(ITYPE,JSPEC,KSPEC)+SLOPE(ITYPE,
     %JSPEC,KSPEC)*CAP1*DIST+EQUIPM(ITYPE,JSPEC,
     %KSPEC,MSPEC))
      COSTM=COSTM+COSTM1*CTF(NYEAR,JDEP)
      VM=VM+COSTM1*VNNEX(JDEP)
      GO TO 19
      END
C ********************END OF THE PROGRAM*************
```

APPENDIX B :TECHNICAL INFORMATION ON CARRIER SYSTEMS

B.1 Transmission

In order to transmit information from point A to point B; the following are necessary:

a) terminal equipment consisting of a sender and a receiver,

b) a transmission medium.

The terminal can be a simple telephone set or a complex multi-channel carrier terminal.

The medium may be a pair of wires, a radio path, a coaxial cable tube etc. Disregarding the radio path, the medium can be divided into two main classes;

a) voice frequency circuits (VF)...(on cable - freq. band 300 - 3400 KHZ)

b) carrier frequency circuits...(on cable, 0 - 24KHZ)

The carrier technique is divided into two broad sub-sections.

1. Frequency Division Multiplexing (FDM) - where individual VF circuits are translated from high frequency bands and are 'stacked' or 'multiplexed' in frequency for transmission over a common medium such as a cable pair.

2. Time Division Multiplexing(TDM) - where individual circuits are "sampled"in time and the samples are

interleaved and "coded" for transmission over a common medium such as a cable pair.

'FDM' is 'analogue' in nature while TDM is 'digital' in nature.

B.1.1 Analogue Carrier (Using FDM)

Figure B.1, shows a simple three channel analogue carrier system.

Using three identical VF circuits (0 - 4KHZ), two of the signals are "modulated" to higher frequency bands and sent to the common cable pair. The combined three channels have a carrier frequency of 0 - 20 KHZ with each channel separated in frequency. If the reverse process is done at the receiving end, each channel is converted back to the original VF frequency.

The above process is termed as "amplitude modulation"; another type of carrier uses "frequency modulation".

B.1.2 Digital Carrier (Using TDM)

Digital carrier is also divided into two or more modulation schemes, of which Pulse Code Modulation (PCM) is in widespread use today.

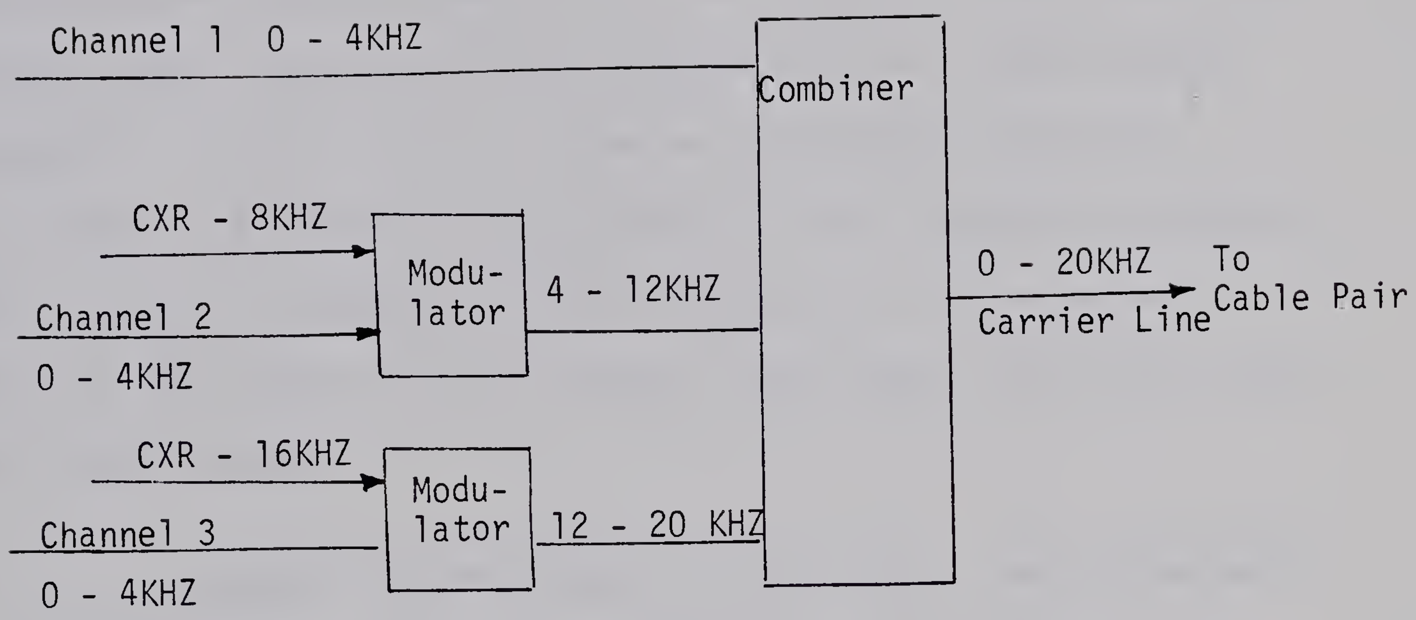

Figure B.1 Three Channel Analogue Carrier System

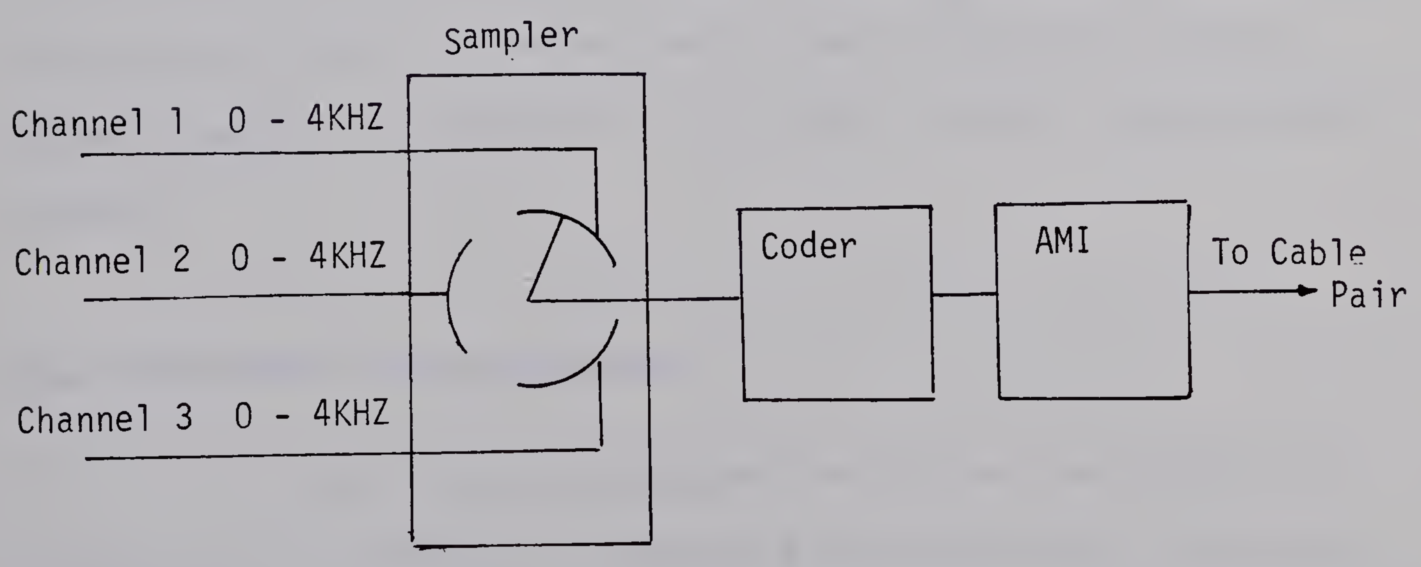

Figure B.2 Three Channel Digital Carrier System

In Figure B.2, the sampler is an electronic device which samples each VF channel individually in sequence. It produces one complete set of three samples, 8000 times per second. This sequence is now applied to the coder which assigns a unique code or sequence of binary pulses to represent the height or amplitude of the incoming signals. That is the VF information is carried in the sequence or code of the ON/OFF binary pulses, and hence the name "Pulse Code Modulation".

Before transmitting to the cable, the 'Alternate Mark Inverter' (AMI) reverses the polarity of every other pulse in order to reduce the average d.c voltage level of the binary signal to zero. This simplifies the design of the line repeater required to regenerate the signal. When the signal has travelled a long distance, it is considerably attenuated and distorted. A line repeater (not an amplifier) then regenerates or reconstructs the distorted incoming pulse signal to produce as its output perfect undistorted signal.

B.2 Subscriber Carrier System

A few of the subscriber carriers are listed in Table B.1. The number of channels indicates the number of simultaneous conversations possible over the carrier system. The pair gain indicates the advantage of the carrier system over the cable pair placement.

B.2.1 Concentrators

In the subscriber systems listed above each channel of the carrier system is dedicated to one subscriber, and 90% of the time each channel is idle and earning no revenue. Better use of the carrier system can be made possible by using concentrators. In this situation many subscribers share the available channels back to the switching center on a first come first served basis.

In Figure B.3, 32 subscribers are connected to the switching center, each being dedicated one channel. In Figure B.4, 128 subscribers are connected to the switching center. By addition of concentrator switches, 128 subscribers can use the same facilities previously required for 32 subscribers. The concentrator connects a subscriber requiring dial tone to the first free channel but of course no more than 32 subscribers can talk simultaneously. However, since each phone is used very little, the chance of call blocking is low.

Using concentration, the maximum pair gain available with the previously listed carriers is as shown in Table B.2.

B.2.2 Digital Carriers in Conjunction With Digital Switching Machines

Pair gain devices were previously considered

Table B.1 Information Relating to Some Subscriber Carriers

Manufacturer	Name	Type	No. of wire Pairs	Channels	Pair Gain
a) Anaconda	56A	Analogue	1	6	1:6
b) Superior Cont.	CM8	Analogue	1	8	1:8
c) ITT	DM 32S	Digital	2	32	1:16
d) Northern Telecom	DMS 1	Digital	4	48	1:12

Table B.2 Pair Gains for Different Carriers

System	Pair Gain
S6A	1:24 (ES-1 Concentrator)
CM8	1:24 (ES-1 Concentrator)
DM32S	1:64 (Built in Concentrator)
DMS1	1:64 (Built in Concentrator)

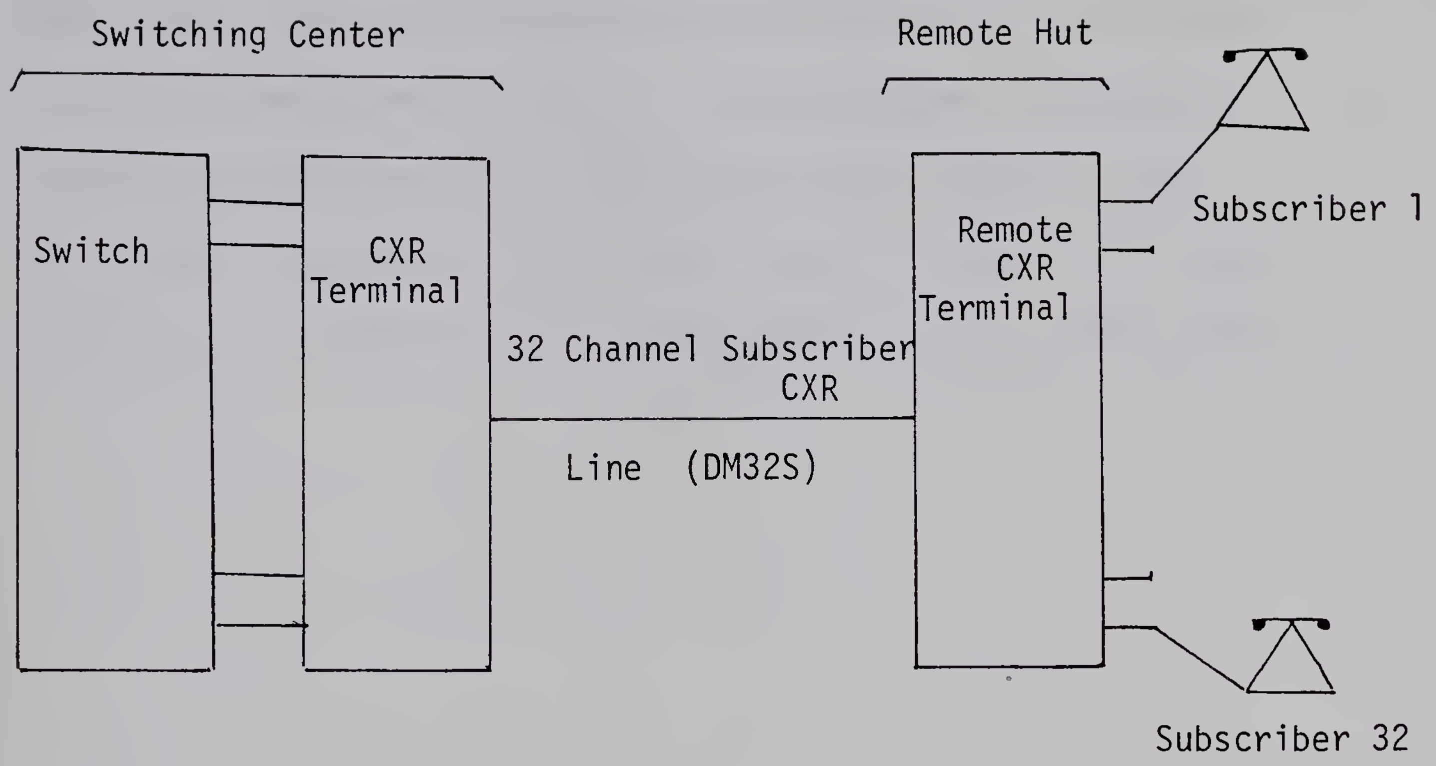

Figure B.3 Subscriber Carrier Without Concentrator

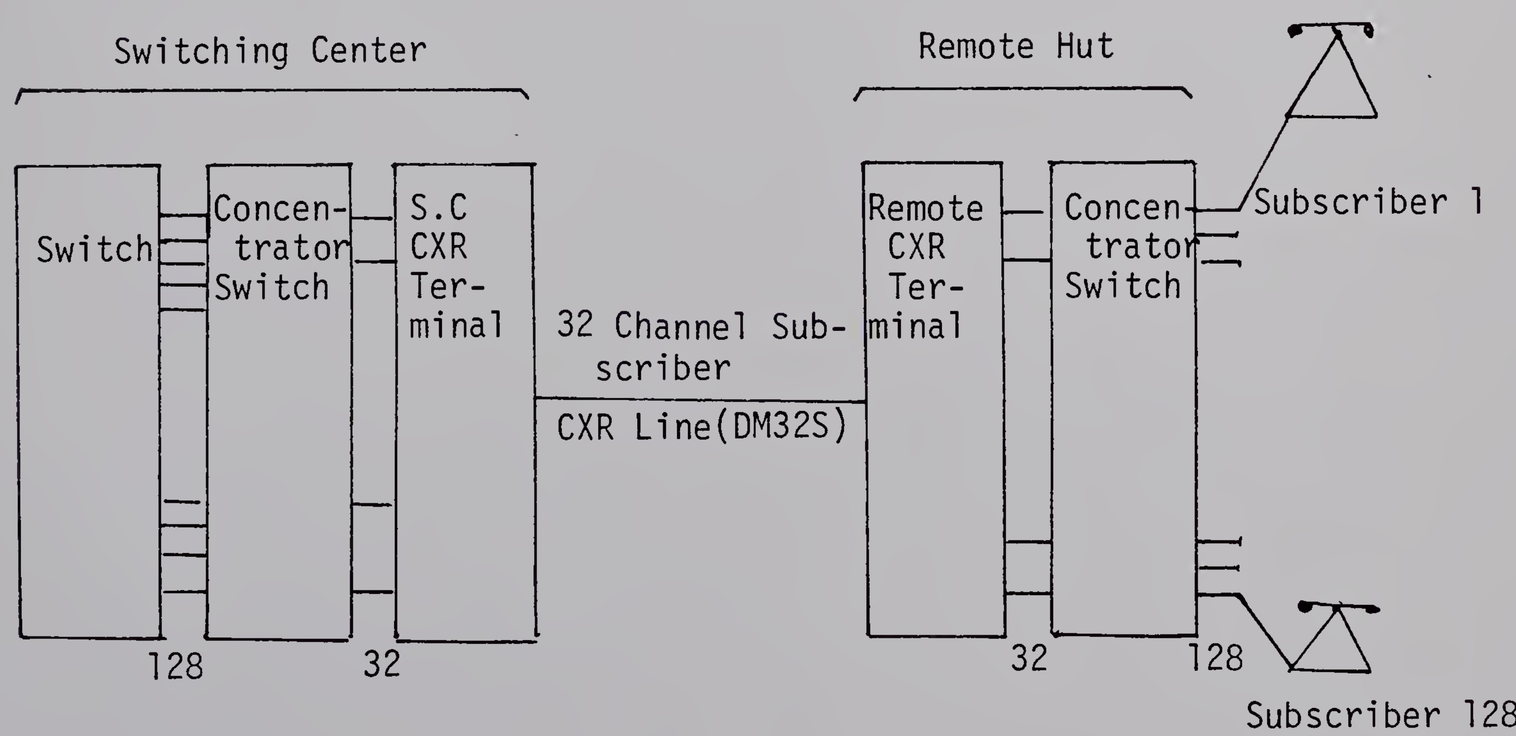

Figure B.4 Subscriber Carrier With Concentrator

(Carrier, concentrators) working on existing analogue switching machines. With the introduction of digital switching machines the office terminal (OT) of the subscriber carrier is no longer needed. The T-CXR line is directly accepted by the switch without any conversion.

APPENDIX C :THE S CURVE PARAMETERS

The technology curve parameters 'A' and 'k' are obtained from the envelope curve as suggested below. The carrier companies can plot the envelope curve and extrapolate it to obtain the ordinates of the curve in the future years. From these values the representative parameters of the curve can be obtained by simple linear regression of a transformed variable.

In the 'S' curve equation;

$$f(t) = f(to) - f(to)/(1+A.EXP(-kt))$$

Since f(to) is the ordinate of the curve in year 0, while normalizing this value becomes equal to 1.

Therefore,

$$f(t) = 1 - 1/(1+A. EXP(-kt))$$

if Z, a new variable is made equal to 1/(1+A* EXP(-kt)), then,

$$\ln A - k.t = \ln[(1-Z)/Z] \qquad ,Z<1$$

$$\ln[Z/(1-Z)] = k.t - \ln A$$

A linear regression of ln [Z/(1-Z)] versus t will give the intercept and the line, from which;

k = slope of the line, and

A = - EXP(intercept).